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THE ACTUAL LATERAL PRESSURE OF EARTHWORK.

By BENJAMIN BAKER, M. Inst. C.E.

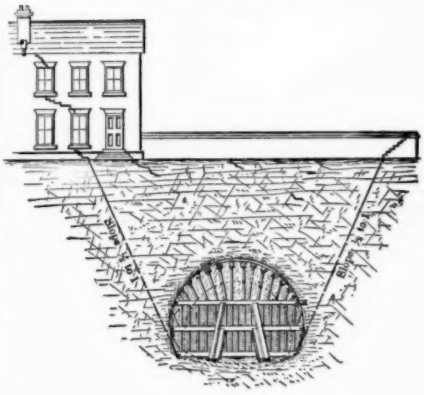
Proceedings of the Institution of Civil Engineers.

II.

HAVING thus briefly reviewed some direct experiments on the actual lateral thrust of earthwork, the author proposes to revert to the consideration of indirect experiments, dealing first with a few of those arising on the 34 miles of deep-timbered trenches and other works of the "underground" railway.

In tunneling very valuable evidence was afforded of the direction of the line of least resistance in a mass of earthwork. From the coming down of the crown bars, the changing of props, the crushing of timber, the compression of green brickwork and other causes, a settlement of from 6 to 8 inches usually occurred overhead, with a general draw of the ground towards the working end of the tunnel and the formation of fissures, attaining a maximum size where the line of least resistance cut the surface. Even when the settlement was slight, fissures were invariably observed in advance of the working end, and in continuous lines running parallel with the tunnel. The slope of these fissures was so uniformly at the angle of $\frac{1}{2}$ to 1, measuring from the bottom of the excavation (Ex. 24, Fig. 5), that the resident engineer professed to be able to foretell with certainty where a building or fence wall, standing over the tunnel, would crack most. Assuming this $\frac{1}{2}$ to 1 to represent Coulomb's line of least resistance, then the corresponding natural slope of repose of the material would appear to be $1\frac{1}{2}$ to 1, which is considerably steeper than what it was in fact.

Fig.5



There is nevertheless a closer accord than usual between theory and fact in the instance of the several miles of fissures, which occurred during the construction of the tunnels of the Metropolitan railway. In other instances, such

as the failure of ill-devised timbering, or the pushing forward of a retaining wall, by heavy clay pressing against its lower half, this accord was not always exhibited. In some cases no previous fissures have occurred, but a wedge of 1 to 1 has at once broken off and gone down with the timbering, whilst in others the fissure has appeared immediately at the back of the wall; indeed in one instance, for several consecutive weeks, the author was able to pass a rod, 15 feet long, between the wall and the apparently unsupported vertical face of the ground behind it. The corresponding theoretical slope of repose would thus appear to be horizontal in one case and vertical in the other, which is sufficient evidence of the necessity of giving but a qualified assent to any theoretical deduction affecting the line of least resistance in earthwork.

A very fair notion of the relative intensity of lateral and vertical pressure in earthwork is often obtained in carrying out headings. The heading for the Campden Hill tunnel of the Metropolitan railway is a case in point (Ex. 25). The ground consisted of sand and ballast, heavily charged with water, overlying the clay through which the heading was driven, at a depth of 44 feet from the surface. After the heading had been completed some months, the clay became softened to the consistency of putty by the water which filtered through the numerous fissures, and the full weight of the ground took effect upon the settings. Both caps and side trees showed signs of severe stress throughout the entire length of the heading, and the occasional fractures in the roof and sides indicated that the timbers were proportionately of about the same strength, or rather weakness. The caps were of 14-inch square balks, with a clear span of 8 feet, and the sides of 10-inch square timber, with a clear span of 9 feet. Their respective powers of resistance per square foot of poling boards, supported, would therefore be as $\frac{14^2}{8^2} : \frac{10^2}{9^2} = 3\frac{1}{2} : 1$.

Now if one thing is settled by experience beyond all question, it is that the superficial beds of London Clay, sodden, as in the present case, with water, will not take a less slope of repose than 3 to 1. The average weight of the wet ground over the heading being about 1 cwt. per cubic foot, the theoretical lateral pressure on the side trees, at a mean depth of 48 feet from the surface, would be (see table) $= 48 \times 0.52 \times 1$ cwt. $= 25$ cwt. per square foot, and upon the caps $= 44 \times 1$ cwt. $= 44$ cwt. per square foot, or 1.76 time greater. But the side trees, as has been seen, had only $\frac{1}{3.5}$ of the strength of the caps, so the irresistible conclusion is that the actual lateral pressure of the earthwork in this instance did not exceed one-half of that indicated by theory.*

It is readily shown that the full weight of the ground came upon the settings. Thus, assuming it to do so, the weight upon the caps would be $=44$ cwt. $\times 8$ feet clear span $\times 3.5$ feet distance apart of the settings $= 1{,}232$ cwt., and taking the effective span at 9 feet, the breaking weight, upon the basis of Mr. Lyster's experiments on balks of similar size and quality, would be $\frac{2 \times 14^{2\prime\prime} \times 2.03 \text{ cwt.}}{9'} =$ 1,240 cwt.; hence the occasional fractures of the balks are fully accounted for. Indeed, the heading would have entirely collapsed, in the course of time, had not the roof been supported by intermediate props practically quadrupling its strength.

In the early days of the construction of the Metropolitan railway, a definite type of timbering had not been arrived at, and some remarkably light systems were tried at times. The lightest the author remembers was the timbering of the 14-feet wide gullet at Baker Street station (Ex. 26). Here the soil cut through was made up of about 8 feet of yellow clay and gravel, 7 feet of loamy sand, 7 feet of sharp sand and gravel, full of water, and 4 feet of London clay at the bottom of the gullet. The timbering of the lower half consisted of 9-inch by 3-inch walings, 3 feet apart from center to center, in 12-feet lengths, with $\frac{3}{4}$-inch poling boards at the back. With one-half the distributed breaking load, the deflection of this 3-inch deep beam at the span of 12 feet would be at least 4 inches, whilst the ultimate deflection would be measured by feet. As the walings did not bend nearly as much as 4 inches, it will be a liberal estimate to assume that the actual lateral pressure of

* See also "Zur Theorie des Erddrucks," Weyrauch Zeitschrift für Baukunde, vol. i., p. 192,

the earthwork was equal to half the distributed breaking weight of the waling. Having reference to the quality of the timber, this may be estimated at $\frac{3''' \times 9'' \times 2.6 \text{ cwt.}}{12' \, 0''} = 17.6$ cwt.; and since the area of the poling boards supported by each waling was 36 square feet, it follows that the lateral pressure of the earthwork could not have exceeded 55 lbs. per square foot. But the depth of the bottom waling below the surface was 23 feet, or, neglecting the clay, and taking only the sharp sand and ballast charged with water, the depth would still be 20 feet, and the weight of fluid corresponding to the 55 lbs. per square foot pressure no more than 2.75 lbs. per cubic foot.

It will be remembered that the natural slope of the sand and ballast in Lieutenant Hope's retaining-wall experiments was about $1\frac{1}{8}$ to 1, and that the actual and theoretical corresponding fluid pressures were respectively 10.3 lbs. and 23.6 lbs. per cubic foot. In the case of the gullet, the natural slope of the ballast and sand would similarly be not less than $1\frac{1}{8}$ to 1, and yet the fluid pressure could not have exceeded 2.75 lbs. This one fact, therefore, is sufficient to prove that the universal assumption of the pressure of earthwork being analogous to that of fluid, and proportional to the depth, is one of convenience rather than truth. The explanation of the singularly small lateral thrust of the ballast in the present case is to be found in the fact that the ballast was lying between, and partially held back by, the two relatively tenacious layers of loamy sand and clay. As an extreme example of the same kind of action (Ex. 27), the author may state that he once applied to a wooden box full of sand a pressure equivalent to a column of that material 1,400 feet high before the box burst. On the fluid hypothesis, the lateral pressure would have been 1,400 feet $\times$ 23.6 lbs., or about 15 tons per square foot; but of course a few lbs. would have burst the box, and the sand was retained by being jammed between the bottom and lid of the little deal box—the equivalents of the tenacious strata in the gullet.

In shafts the stress on the timbering is far less than in a continuous trench or heading, by reason of the frictional adhesion and tenacity of the adjoining earth. Thus (Ex. 28) at a depth of between 40 and 50 feet, 10-inch square timbers, 4 feet 6 inches apart, proved of ample strength to support the sides of a 12-feet square shaft, though the same sized timbers at the reduced distance of 3 feet 6 inches apart, failed, as has been seen, to support the sides of a 9-feet square heading.

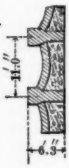
After the experience of several rather troublesome slips, light timbering was abandoned, and a type which proved to be of ample strength to meet all the contingencies of heavy ground, vibration from road traffic, and the surcharge of lofty buildings, was adopted. In this type (Ex. 29) the 14-feet walings increased in scantling to 12 inches by 7 inches, were spaced 7 feet apart, and strutted at each end and at the center. At one-half the breaking weight the supporting power of the walings would be about $\frac{7^2 \times 12 \times 3 \text{ cwt.} \times 112}{6.5^2 \times 7} = 670$ lbs. per square foot, and as the depth of the excavation was in some instances as much as 36 feet, this would correspond to a fluid pressure of 18.6 lbs. per cubic foot. With ground weighing 112 lbs. per cubic foot, and a slope of repose of $1\frac{1}{2}$ to 1, the theoretical lateral pressure would be 32 lbs. per cubic foot; and when it is remembered that this does not include any allowance for the surcharge due to contiguous buildings, and that the stress on the timber is taken at fully half the breaking weight, it is clear that the average actual lateral pressure of the earthwork must have been less than half that indicated by theory.

On the extensions of the Metropolitan railway, the same type of timbering was adopted, but the walings were generally 9 inches by 4 inches, and spaced 3 feet apart. The supporting power, upon the same basis as in the last instance, would be about 430 lbs. per square foot. In most cases this strength proved to be sufficient, but in a few instances the walings broke, or showed such signs of distress that additional support had to be given. This was the case in some of the deep trenches along the Thames Embankment, where heavy wet silt was traversed. Near Whitehall Stairs (Ex. 30) the trenches were 40 feet deep, so the elastic strength of the timbering was

only adequate to the support of a fluid pressure of 10.6 lbs. per cubic foot, or probably but one fourth of that theoretically due to the material; it is therefore no matter for surprise that the walings proved unequal to their work. The stability of the timbering in more moderate depths was, on the other hand, confirmatory of the general deductions

Fig.6

Fig.7



drawn from previous examples as to the wide divergence between the actual and calculated thrust of earthwork.

Turning now from the consideration of the temporary works of timbering to the finished and permanent structures on the underground railway, a similar variation in strength will be found to obtain. The lightest retaining wall on the line is that at the Edgware Road station yard (Ex. 31, Figs. 6 and 7). This wall is 23 feet in height from the top of the footing to the ground level, and has a maximum thickness of but 6 feet 3 inches at the base, out of which has to be deducted a panel 2 feet 6 inches deep. Calculating the moment of stability at the level of the footings and round a point 3 inches back from the face of the pier—which is a sufficient allowance for the crushing action on the brickwork—M=4.4 feet,× 8,800 lbs. = 38,720 foot pounds per lineal foot of wall. Dividing by $\frac{h^3}{6}$, then 19 lbs. per cubic foot is the weight of the fluid which would overturn this retaining wall. The ground supported is light dry sand, having a slope of repose of about $1\frac{1}{3}$ to 1, and consequently exerting a theoretical lateral thrust equivalent to a 24-lb. fluid. There is practically no tenacity in the soil, as the author remembers seeing demonstrated on one occasion when a horse and cart, approaching too near the top edge of the slope, broke it away and rolled together to the bottom of the 23 feet cutting. Although theoretically deficient in stability, and subject to heavy vibration from the two minutes train service, the wall has stood perfectly without exhibiting the slightest movement. Upon the basis of the results of actual experiments, and having reference to the character of the soil and other conditions, the factor of safety would appear to be about 2 to 1.

A far lower factor sufficed to secure the temporary stability of the dry areas at the station buildings previous to the erection of the arched roofs (Ex. 32). The arrangement at Sloane Square station is shown in Figs. 8 and 9. The joint stability of the front and back walls is the same as that of a solid rectangular wall having a thickness equal to $(2.4 \times 2.5 + 3.8 \times 5.2)^{\frac{1}{3}} = 5.1$ feet, or say $\frac{1}{6}$ of the height. A fluid pressure of about 9 lbs. per cubic foot would upset such a wall, so the factor of safety, until the arched roof abutted against the dry areas, was only that due to the few 14-inch brick arches which tied the walls together with a certain amount of rigidity. This result would perhaps have surprised the author more had he not previously investigated many cases of

Fig.8

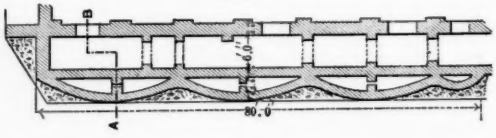
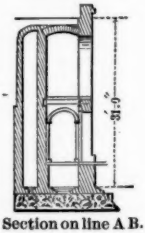


Fig.9



Section on line A B.

old timber wharves, in which the piles and planking had lost more than ¾ of their original strength from decay, and yet held on against a theoretically overpowering thrust of earthwork.

The relatively strongest wall on the Metropolitan railway system is at the St. John's Wood Road station (Ex. 33), and that has given considerable trouble. Though 8 feet 6 inches thick at the base, and backed up to a height of 16 feet only out of the total height of 21 feet 6 inches, and supported at the top by the thrust of the arched roof of the station, this wall moved over and forward to an extent which necessitated the immediate adoption of remedial measures.

It is a suggestive fact that, out of the 9 miles of retaining wall on the underground railway, the exceptionally weak wall should show no movement either during or after construction, whilst the exceptionally strong wall, though having six times the stability of the former, should fail. If an engineer has not had some failures with retaining walls, it is merely evidence that his practice has not been sufficiently extensive; for the attempt to guard against every contingency in all instances would lead to ruinous and unjustifiable extravagance, and be indeed as ridiculous a proceding as the making every soft clay cutting at a slope of 10 to 1, because in a few places such cuttings happen to slip down to that slope.

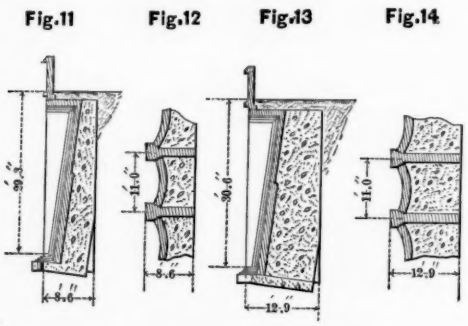
Fig. 10.

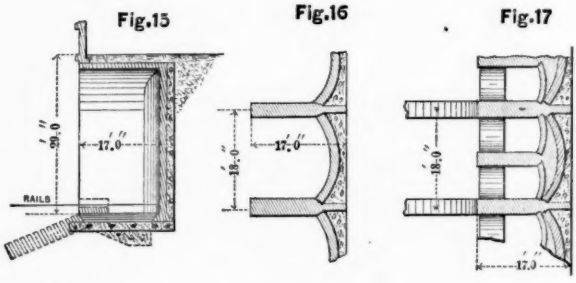
The moment of stability per lineal foot M=73,000 foot pounds, consequently dividing by $\frac{16^3}{6}$ the fluid resistance is 107 lbs. per cubic foot, or allowing for the thrust of the arched roof of the station, considerably greater than that of a perfect fluid having the same density as the ground supported. It is not contended that such a pressure ever occurred upon the wall, although the ground is heavy yellow clay. The failure arose from causes which will be referred to more generally hereafter, and the case is only mentioned as a signal instance of the futility of hoping to reduce the engineering of retaining walls to the form of a mathematical equation.

In two instances comparatively heavy retaining walls have failed on the Metropolitan railway. During the construction of the line, the wall on the west side of the Farringdon street station, (Ex. 34), failed bodily by slipping out at the toe and falling backwards on to the slope of the earthwork (Fig. 10). This wall (Figs. 11 and 12) was 29 feet 3 inches high above the footings, and 8 feet 6 inches thick. The ground consisted of about 17 feet of made ground, 3 feet of loamy gravel, and 9 feet of clay. At a distance of 15 feet from the back of the wall, and at a depth of 15 feet from the surface of the road, was the Fleet Sewer—a badly constructed and much

broken brick barrel, 10 feet 6 inches diameter and 3 rings thick. It was believed that the leakage from the sewer induced the failure of the wall, but in reconstruction both wall and sewer were strengthened. The latter was made 4 rings thick in cement, and the former (Ex. 35) was increased in thickness to 12 feet 9 inches (Figs. 13 and 14). Originally the stability was equal to the resistance of a fluid pressure of 24 lbs. per cubic foot, and, as reconstructed, to 54 lbs.

On the opposite side of the same station yard the ground was retained by a line of vaults (Ex. 36, Figs. 15 and 16), 29 feet high above the footings, and 17 feet deep—or double the original thickness of the wall last referred to. Although the resistance to overturning was greater in the proportion of 62 lbs. to 24 lbs. per cubic foot, the vaults some years after construction came over 15 inches at the top, and slid forward considerably more. The movement when once fairly commenced was rapid and alarming, as a mass of densely inhabited houses was within 20 feet of the back of the vaults. Steps were promptly taken to strengthen the work, by building intermediate piers and doubling the thickness at the back (Ex. 37, Fig. 17). This arrested the movement for a few months, when the vaults, whose stability had been thus increased to 93 lbs. per cubic foot, again began to go over and slide forward. It was clear that mere weight would not insure stability, so 3-feet square brick struts were carried at intervals from the toe of the piers across and under the railway to the retaining wall of the low-level line traversing the station yard, at a distance of about 34 feet from, and 8 feet below, the level of the footings of the vaults.





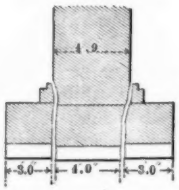
The soil in the preceding instance consisted of about 12 feet of made ground overlying the clay, and, as in the former case, a sewer was to be found rather close to the back of the work. West-

ward of the vaults, the clay encountered in the construction of the line was hard blue clay, requiring the use of a pick, and portions of the temporary cuttings in the station yard, on the site where the vaults were subsequently built, stood fairly for many months at a slope of $1\frac{1}{2}$ to 1. At one point, however, troublesome slips occurred, and even a 2 to 1 slope had to be piled at the toe to prevent forward movement. It was at this point that the vaults were subsequently found to be most dislocated.

In neither of the above cases was failure due to a deficient moment of stability in the wall, and therefore the fact of their failure does not in any way conflict with the results of the experiments previously set forth. In each case water at the back of the wall was as usual the active agent of mischief—not in thrusting the wall forward by hydrostatic pressure, but in softening the clay and affording a lubricant, so that the resistance was reduced to a sufficient extent to enable the otherwise innocuous lateral pressure of the earthwork to tilt and thrust forward the wall.

A costly, but conclusive, experience of this softening action was obtained in the instance of the central pier to the double covered way on the District railway near Gloucester Road station (Ex. 38). The weight per lineal foot was 21 tons per foot run of pier, and 4 feet 9 inches was spread out by footings and concrete to a base of 10 feet; hence the pressure on the ground was 2.1 tons per square foot. In a similar construction near Aldersgate the load was 25 tons, and the width of base 8 feet 3 inches, giving the increased load of 2.9 tons upon the foundations. At the Smithfield market the author did not hesitate to place a column carrying 435 tons upon a 12-feet-square base, which is equivalent to a load of 3 tons per square foot; and in the Euston Road, the side wall of the covered way has a load of 15 tons per lineal foot on a 4-feet-wide base, which is at the rate of $3\frac{3}{4}$ tons per square foot. In all instances the foundation was clay, of apparently equal solidity, and in every instance but the first no settlement at all occurred. For some years no settlement was observable in that case either, but ultimately, after an accidental flooding of the line, and permanent accumulation of water near the foundations, owing to the line being below the limits of natural drainage, and the pumping being neglected, cracks were observed in the arches, and on examination the concrete and footings of the central pier were found to be fractured, as shown in Fig. 18. The load of 21 tons per lineal foot was thus imposed upon a base only 4

Fig.18



feet wide, and the softened clay proved unable to sustain the pressure of upwards of 5 tons per square foot. Considerable difficulty was experienced in checking the movement when once established. The center pier was underpinned with brickwork in cement, but the footings, though of exceptional strength, were again sheared off, and it was found necessary to use 6-inch York landings.

This failure shows the advisability of making concrete foundations of sufficient transverse strength to distribute the weight uniformly over the ground. As the result of experiment, the author is of opinion that the ultimate tensile resistance in a beam of good cement or lias lime concrete, is about 100 lbs. per square inch, and in a beam of good brickwork in cement as much sometimes as 350 lbs. per square inch.* Taking the former value (Ex. 39), a 12-inch thick concrete foundation, projecting 12 inches from the face of a wall, would break with a distributed load $= \frac{12' \times 100}{6 \times 6} = 4{,}800$ lbs.; or, say, 2 tons per square foot. With a pressure upon the foundation of, say, 3 tons per square foot, and a factor of safety of 2, the thickness of a concrete foundation would therefore be $\sqrt{\frac{3 \text{ tons} \times 2}{2 \text{ tons}}} = 1.73$ time the amount of

* *Vide* "The Strength of Brickwork." By B. Baker. "Engineering," vol. xiv.

its projection beyond the face of the pier or wall, and the author would not advise a less thickness being used when the foundation rests on plastic clay.

Water naturally gravitates to the foundation of a retaining wall, and a softening occurs. Owing to the lateral thrust of the earthwork, the pressure on the foundations is not uniform, and instead of settling uniformly, the outer edge descends fastest and the top of the wall is thrown outwards. The same softening reduces the clay to a condition in which it is easily ploughed up by the advancing wall, and the water acts as an admirable lubricant in diminishing the friction between the bottom of the wall and the clay on which it rests. These elements are exceedingly variable in their nature, and it is practically impossible to foretell the extent of their influence in each individual case.

In tunneling, clay may be the best or the worst of materials—almost self-supporting, or pressing with irresistible force on the crushing timbers and brickwork. It may be taken for granted that in good ground bad work will occasionally creep into tunneling, however close the inspection. How good a material clay can be was enforced upon the author's attention once in renewing a short length of defective tunnel lining, when on cutting down the work it was found that for some 50 feet the side wall, instead of being 2 feet 6 inches thick as intended, consisted merely of a skin of brickwork 9 in inches thick on the face, with a number of dry bats thrown in loosely behind this thin face wall to fill up the space excavated. This tunnel (Ex. 40) was loaded with a weight of 46 feet of clay over the crown, but no measurable settlement had taken place ten years after completion, and it was rather by sounding the side wall, than by the observance of cracks, that a suspicion was raised as to its solidity. If the full weight of the ground had come upon the tunnel as it did upon the heading (Ex. 25), the pressure upon the side wall would have been 45 tons per lineal foot, or practically double the strength of the 9-inch work as determined by experiment.

Of course the clay in this case was hard blue clay, which had not been affected by the action of air and moisture. As explained by the Rev. J. C. Clutterbuck, many years ago, the superficial layers of the London clay are yellow, because the protoxide of iron is changed into a peroxide by the action of air and moisture in the disintegrated mass, and it is the yellow clay, therefore, which is the dread of the engineer. As good an example as any of the difference between the two materials was afforded forty years ago, in the well-known slip which occurred in the 75-feet-deep cutting at New Cross, when nearly 100,000 tons of yellow clay slipped forward on the hard smooth surface of the shale—like underlying blue clay, and buried the entire line for a length of more than a hundred yards to a depth of 12 feet.*

Owing to a misunderstanding, a section of concrete wall designed by the author to form one side of a running shed, and to retain the earthwork in a 13-feet cutting through light-made ground, was adopted also in a similar case, but where the ground was heavy wet clay, and the cutting 30 feet deep (Ex. 41). A wall 13 feet in height from formation to coping, and only 3 feet 3 inches thick at the base, had thus to sustain a surcharge of 17 feet. As the slope of repose was at least $1\frac{1}{2}$ to 1, the lateral thrust was theoretically equivalent to a fluid pressure of about 70 lbs. per cubic foot, whereas a pressure of less than one-third that intensity would have overturned the wall. The latter, nevertheless, held up the ground fairly for some months, though the nature of the soil was such that it ultimately became necessary to add strong counterforts to the wall, and to reduce the slope of the cuttings generally to 2 : 1.

On the Thames Embankment heavy clay filling was in places cut through by the District railway, and in several instances the light side walls of the covered way were thrust over a few inches at the top before the girders were bedded (Ex. 42). The side walls were eighteen feet in height from the invert to the ground level, and 5 feet 6 inches thick, with panels 5 feet 6 inches wide, by about 2 feet 9 inches deep, and piers 2 feet 6 inches wide. A fluid pressure of 16 lbs. would overcome the stability of these walls, but, though subject to the pressure of the

* *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 139.

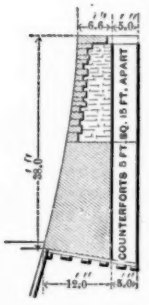
heavy clay filling, none of them failed. The existence of an undue pressure was, however, manifested by the thrusting forward of the green brickwork during the few weeks that the walls were left unsupported by the girders.

The retaining walls, at the approach to Euston Station, afford a good illustration of the impossibility of making any reasonable approximate estimate of the possible lateral thrust of yellow clay, or of stating positively that no movement will ever occur. These walls, soon after construction, were forced out in an irregular way at the top, bottom, or middle, but on pulling them down, the clay behind appeared to be free from fissures and to stand vertical. Cast-iron struts were subsequently put in between the opposite retaining walls; and although General Burgoyne, who had given much attention to the subject of revetments, prophesied at the time that they would be removed in a few years, "when the ground had become consolidated," the struts still remain, and the walls still give signs of severe and increasing stress.

It is not only London clay that proves so embarrassing to engineers. In a recent Paper* particular attention was called to the treacherous nature of some boulder clay which, "although so tough and tenacious as to give the utmost difficulty in excavation, after a short exposure became soft and pasty in the winter, often jolting down the slurry." Examples were given of formidable slips in this material, in contrast with which the author would point to the comparatively slow wasting of the huge boulder clay cliffs near the mouth of the Tyne, a matter which he had occasion to investigate very closely in connection with the Duke of Northumberland's lands in that district. From a comparison of surveys extending over a period of one hundred and fifty years, it appeared that the wasting of the cliff was very slow, and due solely to the wash of the waves at its base. At no time was the slope of repose of this 105-feet-high cliff more than 1 to 1, and in places it stood for years at an average slope of less than $\frac{3}{4}$ to 1. With his experience of North London clay, the author was startled to find people contentedly living in houses partially overhanging the brow of this steep and ragged cliff, but the stability of the clay was so great, and the wasting so uniform, that the fact of the outhouses being at the bottom of the 100 feet slope, and the main building at the top, did not appear in any way to disturb the equanimity of the householders.

The failures of dock walls, though numerous and instructive, afford no direct evidence as to the actual lateral pressure of earthwork, because in practically every instance the failure is traceable to defective foundations. The author cannot recall any case in which a dock or quay wall founded on rock has overturned or moved forward, though on other foundations a movement to a greater or lesser extent is so much the rule that Voisin Bey, the distinguished engineer-in-chief of the Suez Canal, once stated to the author that he could name no exception to it, since he had failed to find any long line of quay wall, which on close inspection proved to be perfectly straight in line and free from indications of movement. A brief examination of some in-

Fig. 19



stances of the failures of dock walls will show how powerfully unknown practical elements affect theoretical deductions in such cases.

A well-known and often cited case is that of the original Southampton dock wall, constructed now some forty years ago (Ex. 43, Fig. 19). This wall, 38 feet in height from the foundation to the coping, was built on a platform of 6-inch planks, resting on a sandy and loamy bottom. Before the water had been let

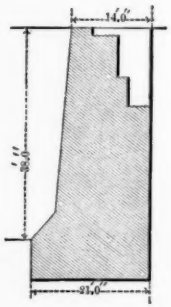
Vide "Earthwork Slips," Minutes of Proceedings Inst. C. E., vol. lxiii., p. 280 *et seq.*

into the dock, or the backing carried to the full height, the wall moved forward in some places as much as three feet, but came over hardly anything at the top. When the water was let into the dock, the filling behind becoming saturated, the pressure on a receding tide exaggerated, and to secure stability it was found necessary to discontinue the filling at some distance below the full height of the wall, and to substitute a timber platform.

The thickuess of this wall at the base is 32 per cent. of the height between the buttresses, 45 per cent. at the buttresses, and a rectangular wall containing the same quantity of material would have a thickness equal to 26 per cent. of the height. Though the base is wide, the weight is light as compared with most other dock walls, and the tendency to slide forward is therefore greater. If founded on a rock bottom, a fluid pressure of about 40 lbs. per cubic foot would have been required to overturn the wall, but of course a fraction of this pressure would suffice to make it move forward on the actual bottom.

The conclusion drawn by Mr. Giles, M. Inst. C. E., the engineer of the docks, from this and other failures is, that the quality of a dock wall is of little consequence compared with the quantity, and

Fig.20

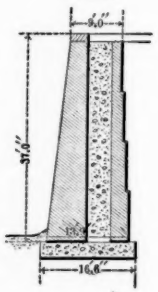


that it ought to be sufficiently strong not only to hold any amount of backing put against it, but to carry a head of water equal to its height if it were left dry on the other side.*

These principles have been adhered to in the recent extension of the Southampton docks (Ex. 44, Fig. 20). Here the wall is founded on a mass of concrete 21 feet wide; the effective thickness at base is about 45 per cent, and the mean thickness 41 per cent. of the height. A fluid pressure of from 60 to 70 lbs. would be required to overturn this wall if on a hard foundation, and probably as much to make it move forward, unless the bottom were of clay or of other unfavorable material. Mr. Giles has found even a heavier wall slide, when founded on a thin layer of gravel overlying clay. In the earlier wall, if the co-efficient of friction of the base on the ground were less than $\frac{2}{3}$, the wall would slide rather than overturn; but in the latter wall, without buttresses, any co-efficient exceeding $\frac{1}{2}$ would be sufficient to prevent sliding.

For comparison with the above, the section of the east quay wall of the Whitehaven dock may be next referred to (Ex. 45, Fig. 21). Having the same

Fig.21



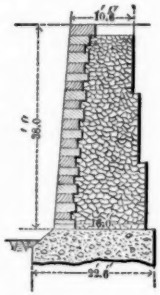
height as the Southampton dock wall, the thickness at the base is but 37 per cent of the height, the mean thickness 31 per cent., and the concrete foundation 16 feet 6 inches, instead of 21 feet wide. This wall has stood perfectly, though it would fail to resist the head of water mentioned by Mr. Giles, but would be overturned by a fluid weighing from 45 to 50 lbs. per cubic foot. During construction, weep holes were, however, left in the walls to relieve them of hydrostatic pressure.

Another dock wall of the same height as the preceding ones, is that of the Avonmouth dock (Ex. 46, Fig. 22). In this instance the thickness is 42 per cent.

* *Vide* Minutes of Proceedings Inst. C. E., vol. lv., p. 52.

of the height, and the concrete base 22 feet 6 inches wide, dimensions which, with a good foundation, would enable the wall to stand a full hydrostatic pressure at the back. Owing to the treacherous nature of the bottom, a long length of this wall nevertheless slipped forward at one point as much as 12 feet 6 inches, and sunk 4 feet 6 inches without the latter being affected, whilst at another

Fig.22

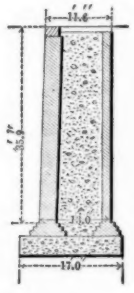


point, where there was no forward movement, the wall came over about 1 foot 8 inches. When the failure occurred, the foundation rested on apparently stiff blue clay, but in subsequent portions the concrete was carried down through the clay to the sand.* On the east side of the dock, though the walls were founded at an average depth of no less than 9 feet below the bottom of the dock, they still moved forward in the mass some 15 feet 6 inches, and sunk 7 feet 6 inches, The filling was carefully punned in layers, with material which seems to have stood fairly at a slope of $1\frac{1}{2}$ or 2 to 1, so that the wall theoretically possessed an excess of strength, and yet, owing to the existence of conditions which it was impossible for the engineer to foresee, failures occurred as described.

A somewhat similar case of sliding forward occurred at the New South Dock, West India Docks (Ex. 47, Fig. 23). The wall is 35 feet 9 inches high from the top of the footings to the coping, and 13 feet, or 36 per cent. of the height, thick at the base. The concrete foundation is 17 feet wide, and 6 feet deep below the bottom of the dock, and the fluid pressure required for overturning would be about 45 lbs. per cubic foot. A coefficient of friction of less than $\frac{1}{2}$ would be sufficient to guard against sliding under this pressure, but owing to the existence of a thin seam of soft greasy silt between the hard strata of blue clay upon which the foundations rested, several portions of the wall slid forward. The original ground level was about 15 feet below the top of the dock wall, and the excavation stood fairly as a slope of 1 to 1. Favorable material for backing did not appear to be available.

The fact that the stability of a dock

Fig.23



wall depends far more upon the foundation than upon the thickness or mass of the wall itself, is well illustrated by the quay wall at Carlingford (Ex. 48, Fig. 24). With a height of no less than 47 feet 6 inches, the thickness of wall and width of foundation at the base are each but 15 feet, or less than 32 per cent. of the height, and the mean thickness is but 24 per cent. A lateral pressure of half that due to a hydrostatic pressure would probably suffice to overturn this structure.

In contrast with the preceding wall may be cited that of the dock basin at Marseilles (Ex. 49, Fig. 25). In both instances the foundation was good, and the wall rested immediately upon it without the interposition of any broad mass of concrete; but the French engineer, though the wall was but 32 feet high, made the thickness at the base no less than 16 feet 9 inches, or 52 per cent. of the height—an unusually large propor-

* *Vide* Minutes of Proceedings Inst. C. E., vol. lv., p. 15.

tion, which he was led to adopt in consequence of the stratification of the ground inclining towards the wall.

Perhaps one of the boldest and most successful examples of a lightly-proportioned wharf wall is that built by Colonel Michon in 1857 on the Moselle at

Fig.24

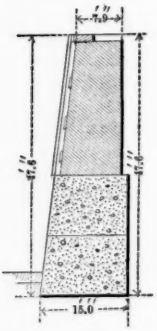


Fig.25

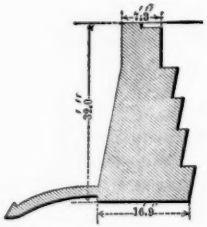


Fig.26

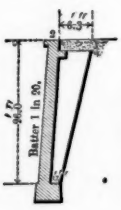


Fig.27

Toul (Ex. 50, Figs. 26 and 27). With a height of 26 feet, and a batter of 1 in 20, the thickness of the wall through the counterforts is but 3 feet 7 inches at the base, and though the filling is ordinary material, having a slope of repose of $1\frac{1}{2}$ to 1, and the floods rise within 6 feet of the top of the coping, no movement whatever has occurred since the wall was built.

As striking a contrast as could be wished to the above light construction is found in Sir John Macneill's quay wall at Grangemouth harbor (Ex. 51, Fig. 28). Both walls are of about the same height, but whilst the mean thickness of the first is only 3.7 feet, or $\frac{1}{7}$ of the height, that of the second, inclusive of the mass of concrete backing, is no less than 23 feet, or, say, $\frac{4}{5}$ of the height.

One of the most troublesome cases of dock-wall failures was that at the Belfast harbor* (Ex. 52, Fig. 29). This wall was founded upon round larch piles 15 feet long, 10 inches in diameter at the top, and 4 feet 6 inches apart from center to center. Symptoms of settlement became apparent soon after the filling was commenced, and some remedial measures were attempted. The ground, however, was hopelessly bad, the slope of repose ranging from 3 to 1 to 6 to 1, and the backing material being equally bad, the light piling was inadequate to resist the thrust. Two years after erection a length of about 70 lineal yards of wall was overturned and carried forward into the middle of the dock entrance, the piles being sheared off about 6 feet be-

Fig.28

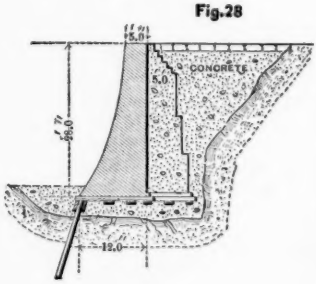


Fig.29

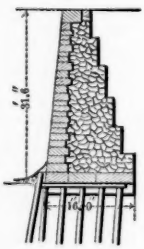
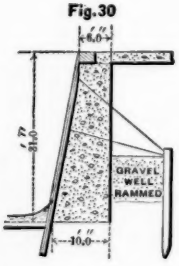


Fig.30



* *Vide* Minutes of Proceedings Inst. C.E., vol. lv., p. 31.

low the bottom of the wall. The height from the top of the pile to the coping is 31 feet 6 inches, and the thickness at the base 16 feet, or half the height. On good ground, therefore, the wall would have had an ample margin for stability.

A somewhat similar failure occurred in the instance of the original side walls of the lock chamber of the Victoria docks* (Ex. 53, Fig. 30). These docks were built at a time when little confidence was placed in concrete as a durable material for dock work, and consequently the walls were faced with cast-iron piling and plates, as in previous instances at Blackwall and elsewhere. The foundations were on a layer of gravel overlying the clay, but the face piling had little hold in the gravel, and the base of the wall itself was only some 30 per cent. of the height, hence, when the water was let into the dock, the hydrostatic pressure at the back of the lock wall forced it bodily forward into the lock, ploughing up the puddle in front of it, and breaking tie bolts and tie piles as it advanced. In reconstruction a solid concrete wall 20 feet thick, and having nearly treble the stability, was carried through the gravel down to the clay.

The wall of the Victoria Dock Extension Works, by Mr. A. M. Rendel, M. Inst. C.E. (Ex. 54, Fig. 31), has a thick-

Fig. 31

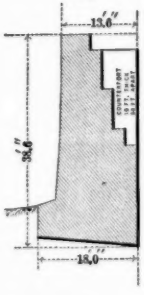
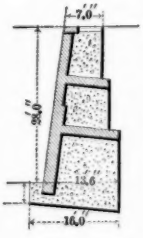


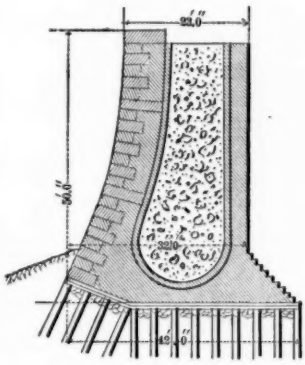
Fig. 32



ness of about 50 per cent. of the height at the point where the 18-feet wide foundation meets what may be termed the body of the wall, and the wharf wall of Mr. Fowler's Millwall dock (Ex. 55, Fig. 32) has a maximum thickness of 13 feet 6 inches for a height of 28 feet from bottom of dock to coping, of practically the same ratio. Either or these walls would be capable of resisting the full hydrostatic pressure.

An early example of a successful wall on a very bad foundation is afforded by Sir John Rennie's Sheerness wall (Ex. 56, Fig. 33). The subsoil consisted of

Fig. 33



loose running silt for a depth of about 50 feet, covered with soft alluvial mud, and the depth at low water was at some points as much as 30 feet. A piled platform about 42 feet in width, with sheeting piles on the river face, and 12-inch piles pitched from 3 to 4 feet apart over the whole area, and driven until a 15-cwt. monkey falling 25 feet did not move them more than ½ inch at a blow, was prepared, and upon this the wall, no less than 50 feet in extreme height and 32 feet in effective thickness at the base, was raised. In no case has any yielding or unequal settlement taken place, except in the instance of the basin wall, the cracks in which Sir John Rennie attributed to other causes than a failure in the foundation. Although the voids in the masonry were designedly filled in with grouted chalk and other light material, the Sheerness river wall has perhaps a greater moment of stability than any other wall in the world.

Another exceptionally heavy wall, more than a half century younger than the preceding, is that of the Chatham Dockyard Extension (Ex. 57, Fig. 34). The height from the bottom of the dock to

* *Ibid.*, vol. xviii., p. 402.

the coping is 39 feet, and the foundations are carried down to the loam gravel or chalk at a depth of 4 feet 6 inches below the bottom of the dock. The thickness of the wall is 21 feet at the base, or, say, $\frac{1}{2}$ of the extreme height.

Walls made of large concrete blocks, resting upon a mound of rubble, have been constructed in many of the Mediterranean ports, generally with success, but occasionally with failure, as at Smyrna, where, owing to the great settlement,

Fig.34

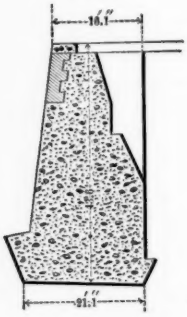


Fig.35

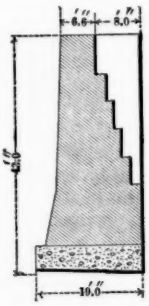
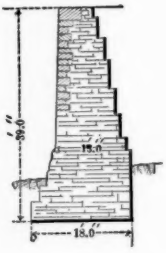


Fig.36



On a hard chalk bottom it would resist a fluid pressure of about 80 lbs per cubic foot.

Two examples of Liverpool dock walls, namely, that at the Canada half-tide basin, and that at the Herculanean docks, are given in Figs. 35 and 36. The six and seven tiers of blocks had to be superimposed instead of four, as intended, and the quay wall had after all to be supported by a slope of rock in front extending up to within 7 feet of mean sea level, and seriously interfering with the use of the quays. The propor-

Fig.37

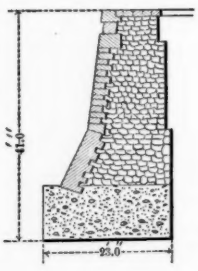


Fig.38

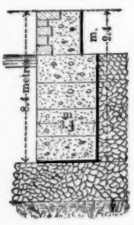
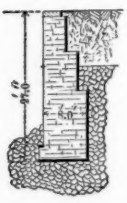


Fig.39



former (Ex. 58) is 43 feet in extreme height, and 19 feet, or 44 per cent. wide at the base. The latter (Ex. 59) is 39 feet high, and 18 feet, or 46 per cent. wide at the footings, which rest on a marl bottom. A dock wall at Spezzia (Ex. 60) of somewhat similar proportions, the height being 41 feet, and the width at the bottom of foundations 23 feet, or 56 per cent. of the height is shown on Fig. 37.

tions arrived at by experience are a width of 9 meters at the top, and a thickness of not less than 2 meters for the rubble mound; a depth of 7 meters below the water line, and a thickness of 4 meters for the concrete block wall resting on the mound; and a minimum thickness of 2.5 meters, and a height of 2.4 meters for the masonry wall coping the concrete blocks.

At Marseilles (Ex. 61, Fig. 38), the

top of the rubble mound is only 6 meters below the water-line, so vessels occasionally bump; and the concrete block wall 3·4 meters, or 40 per cent. of the height, in thickness has proved rather less stable under the contingencies of working and the surcharge of buildings and goods than is considered desirable.

Examples are not wanting, however, of walls founded on rubble mounds where the thickness holds a smaller ratio to the height than the 42 per cent., considered necessary by the French engineers. Mr. Fowler has made concrete block walls in the Rosslare Harbor (Ex. 62) 42 per cent. of the height on the sea face, and but 28½ per cent. on the harbor side, but cross walls at 50-feet intervals considerably strengthen the work. The inner wharf wall of the Holyhead new harbor, again (Ex. 63, Fig. 39), is 27 feet high and 8 feet thick, a ratio of under 30 per cent., but though stable, the line of coping is somewhat wavy on plan. The original wall of the West Pier at Whitehaven (Ex. 64, Fig. 40), is 42 feet 6 inches

Fig.40

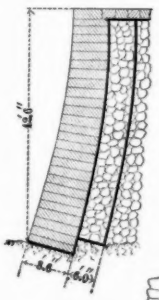
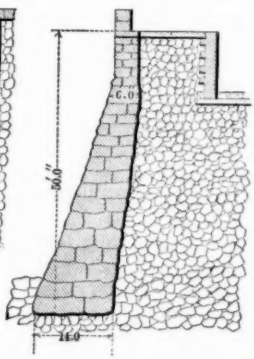


Fig.41



high, with a thickness of 8 feet 6 inches between the buttresses, which latter are 6 feet deep by about 4 feet wide and 15 feet apart; but the lightest of all, perhaps, is the dry masonry outer wall of the St. Katherine's breakwater, Jersey, (Ex. 65, Fig. 41), which is only 14 feet wide at the base for a total height of 50 feet, or a ratio of 28 per cent.

It must not be forgotten, of course, that the three latter walls have to support rubble hearting only, instead of sand and other material, having a much flatter slope of repose. Occasionally, as has been stated (Ex. 22), rubble will not stand at less than 1½ to 1; but at Holy head and Alderney the slope of the rubble mound on the harbor side is only about 1¼ to 1. At Cherbourg it is 1 to 1, and at Leghorn the large concrete blocks are found to be stable at a slope of ⅔ to 1. By a very little care in selection, the thrust of a rubble filling may be reduced to a fraction of that arising from bad material, and indeed in the ordinary run of fishing piers in the North of Scotland, however great the height, the face wall of the rubble-hearted pier consists simply of stones from 3 to 4 feet in depth, laid dry to a batter of about 1 in 5. The north-east pier at Seham, again, has an inner wall 25 feet high, battering 1½ inch to the foot, and only 5 feet thick, and many similar examples are to be found at other points of the coast.

The most cursory examination of cases of failure cited above will serve to justify the statement that the numerous dock-wall failures do not afford any direct evidence as to the actual lateral pressure of earthwork. Thus, remembering General Burgoyne's battering wall, only 17 per cent. of the height in thickness, supported the heavy sodden filling at its back, no calculation is required to show that the 32 and 45 per cent. Southampton Dock counterforted wall, the 42 per cent. Avonmouth Dock wall, the 36 per cent. West India Dock wall, the 50 per cent. Belfast Harbor wall, and the 30 per cent. Victoria Dock wall, would all have stood perfectly had the foundation been rock, as in the instances of General Burgoyne's experimental walls, instead of the mud, clay, and silt which it actually was.

Not only the strength, but the type of cross-section, is singularly indicative of the small influence which theory and experiment have exercised upon the design of dock walls. If the early theorists and experimentalists were in accord upon one point, it was upon the immense advantage afforded by a counterforted wall. Lieutenant Hope was led by his experiments to conclude that if good counterforts were introduced, the merest skin of face wall would suffice for the portion

between them, and theorists of course arrived at the same conclusion, from a comparison of the moments of stability of rectangular blocks of masonry edgewise and flatwise. Nevertheless, in only one of the preceding dock walls, and that one forty years old, are counterforts introduced. In practice it was found that counterforts frequently separated from the body of the wall, and they were consequently regarded as untrustworthy. It is open to question whether this conclusion does not require reconsideration in these days of cheap, strong, and easily-moulded Portland cement concrete. Nothing but blasting would separate the counterforts from a good concrete wall. The author has used concrete in many varieties of structures, and as long back as fifteen years built a four-story warehouse, walls and floors, entirely of concrete, without the introduction of any iron girders. He is bound to admit, however, that by far the boldest and most thorough adaptation of the material to multifarious uses met with by him was in the instance of some farm buildings in an out-of-the-way district in Co. Kerry, Ireland. The small tenant-farmer and his laborers—none of whom were receiving over 11*s.* a week—without skilled assistance of any kind, had constructed dwelling-house, cattle-sheds, and hay-barn wholly of concrete. The cattle-shed was roofed with concrete arches of 15-feet span, 1 foot rise, and 4 inches thick, springing from octagonal concrete pillars 8 inches in diameter, spaced 15 feet apart from center to center. A layer of concrete constituted the paving, concrete slabs divided the stalls, the cattle fed and drank out of concrete troughs, the windows were glazed in concrete mullions, the gates hung on concrete posts, and the farmer seemed to regret somewhat that he had not adopted concrete doors and concrete five-bar gates.

Portland cement concrete being thus possessed of such great tenacity, there is no risk of counterforts separating from the body of a wall, but it by no means follows that there would be any advantage in using them in other than exceptional cases. In practice, as failures have shown, it is weight, with the consequent grip on the ground, rather than a high moment of stability, that is required in a dock wall. It may be asked, with reason why a bad bottom should affect the thickness of a retaining wall, or, in other words, why the foundation should not first be made good, and then a wall of ordinary thickness be built upon it. The answer, of course, is that if weight is required to prevent sliding, it is just as economical to distribute the material over the general body of the wall as to confine it to the foundations. It follows, therefore, that under the stated conditions the adoption of a counterforted wall would lead to no economy in material, whilst it would involve additional labor in construction.

A dock wall is subject to far larger contingencies than an ordinary retaining wall, and the required strength will be included only within correspondingly large limits. Hydrostatic pressure alone may more than double or halve the factor of safety in a given wall. Thus, with a well-puddled dock bottom, the subsoil water in the ground at the back of the walls will frequently stand far below the level of the water in the dock, and the hydrostatic pressure may thus wholly neutralize the lateral thrust of the earth, or even reverse it, as in the case of the inner retaining walls on the Soonkesala canal, some of which, though 35 feet in height, are only 2 feet thick at the top and 7 feet 6 inches at the base. On the other hand, with a porous subsoil at a lock entrance, the back of the walls may be subject, on a receding tide, to the full hydrostatic pressure due to the range of that tide plus the lateral pressure of the filling. Again, the water may stand at the same level on both sides of the wall, but may or may not get underneath it. If the wall is founded on a rock or good clay, there is no more reason why the water should get under the wall than that it should creep through any stratum of a well-constructed masonry or puddle dam, and under those circumstances the presence of the water will increase the stability by diminishing the lateral thrust of the filling. With rubble filling, assuming the weight of the solid stone to be 155 lbs. per cubic foot, and the voids to be 35 per cent., the weight of the filling would be 100 lbs. per cubic foot in air, and 59 lbs in water, and the lateral thrust will be that due to the latter weight.

If, however, as is perhaps more frequently the case, the wall is founded on a porous stratum, the full hydrostatic pressure will act on the base of the wall, and reduce its stability in practical cases by about one-half. Thus, the 30-ton concrete block walls on rubble mounds, at Marseilles and elsewhere, have the stability due to a weight of, say, 130 lbs. per cubic foot in the air, and 66 lbs. per cubic foot in sea water: but the rubble filling at the back of the wall, being similarly immersed, is also reduced in weight, and consequently thrust to a corresponding extent, so the factor of safety is unaffected.

In walls with offsets at the back, as in Figs. 25 and 36, and water on both sides, the stability will be much increased by the hydrostatic pressure on the top of the offsets, should the wall rest on an impermeable foundation. It is generally assumed, in theoretical investigations,* that the weight of earthwork super-imposed vertically over the offsets should be included in the weight of the wall in estimating the moment of stability; but the author has found no justification in practice for this assumption. He has invariably observed that when a retaining wall moves by settlement or otherwise, it drops away from the filling, and cavities are formed. A settlement of but $\frac{1}{32}$ of an inch, after the backing had become thoroughly consolidated, would suffice to relieve the offsets of all vertical pressure from the superimposed earth, and the latter cannot therefore be properly considered as contributing to the moment of stability.

A wall with deep offsets at the back is not a desirable form where the foundation is bad, and where, consequently, the pressure over the foundation should be as uniform as possible, so that a settlement may take the form of a uniform sinking, and not a tilting forward of the coping by reason of the toe sinking faster than the back of the wall. A paneled wall, such as that shown on Figs. 11 to 14, though not admissible in dockwork, is on bad ground far less liable to come over than a wall with offsets at the back, and with a consequent concentration of weight at the front, where the conditions of a lateral thrust especially require that it should not be.

The latter conditions also indicate the expediency of adopting raking piles, as in Fig. 33, rather than vertical piles, as in Fig. 29, where a piled foundation is unavoidable. Thus, taking an ordinary case of dock wall, in which the factor of safety, as regards overturning, is 3, and the ratio of weight of wall to the lateral pressure of earthwork required to overturn it is $1\frac{2}{3}$ to 1, it follows that if the foundation piles are driven at the rate of 1 to $3 + 1\frac{2}{3} = 1 : 5$ there will be no transverse strain tending to break them off, as in the case illustrated by Fig. 29, and no tendency to plough up the soft ground in front of the toe of the wall.

If an engineer could tell by inspection the supporting power and frictional adhesion of every bit of soil laid bare, or see through 5 or 10 feet of earth into a "pot hole," or layer of slimy silt, he might avoid many failures, and even hope to frame some useful equations for obtaining the required thickness of a dock wall. Taking things as they are, however, it is hardly worth while to use even a scale and compass in such work, for being in possession of all the information obtainable about the foundation and backing, an engineer may at once sketch as suitable a cross-section for the particular case as he could hope to arrive at after any amount of mathematical investigation. Something must be assumed in any event, and it is far more simple and direct to assume at once the thickness of the wall than to derive the latter from equations based upon a number of uncertain assumptions as to the bearing power of the foundations, the resistance to gliding, and other elements. This being so, it has often struck the author that the numerous published tables giving the calculated required thicknesses of retaining walls to three places of decimals, stand really on exactly the same scientific basis, and have the same practical value, as the weather forecasts for the year in Old Moore's Almanack. In both cases a pretence is made of foretelling what experience has shown can often not be known until after the event. One well-known authority gives young engineers the choice of five hundred and forty-four different thicknesses for a

* *Vide* "A Manual of Civil Engineering." By W. J. M. Rankine, p. 402.

simple vertical rectangular retaining wall, so that an unfortunate neophyte might not unreasonably conclude that the task before him was not to decide whether, say, a 32-feet wall should be 20 feet thick, as in Example 60, or 9 feet, as in Example 62, but whether it should be 14 feet 6 inches or 14 feet 5½ inches thick.

Although dock wall failures do not afford any data as to the actual lateral pressure of earthwork, a knowledge of the latter will enable much valuable information to be deduced as to the bearing power of soil and other matters from such failures, and the data so obtained will be applicable to other structures beside retaining walls. Knowing the actual lateral thrust, the coefficient of friction of the base of a wall which has been pushed forward on the ground can be at once deduced, but if the theoretical as distinguished from the actual thrust were introduced into the equation, the result would be valueless.

The aim of the author in the present paper has been to set forth as briefly as possible what he knows regarding the actual lateral thrust of different kinds of soil, in the hope that other engineers would do the same, and that the information asked for by Professor Barlow more than half a century ago may be at last obtained. Although the acquirement of the missing data would probably lead to no modification in the general proportions of retaining structures, since these are based upon dearly-bought experience, it is none the less desirable that it should be obtained; for an engineer should be able to show why he believes that a given wall will stand or fall. To assume upon theoretical grounds a lateral thrust, which experiments prove to be excessive, and to compensate for this by giving no factor of safety to the wall, is not a scientific mode of procedure.

Experience has shown that a wall $\frac{1}{4}$ of the height in thickness, and battering 1 inch or 2 inches per foot on the face, possesses sufficient stability when the backing and foundation are both favorable. The author, however, would not seek to justify this proportion by assuming the slope of repose to be about 1 to 1, when it is perhaps more nearly 1½ to 1, and a factor of safety to be unnecessary, but would rather say that experiment has shown the actual lateral thrust of good filling to be equivalent to that of a fluid weighing about 10 lbs. per cubic foot, and allowing for variations in the ground, vibration, and contingencies, a factor of safety of 2, the wall should be able to sustain at least 20 lbs. fluid pressure, which will be the case if $\frac{1}{4}$ of the height in thickness.

It has been similarly proved by experience that under no ordinary conditions of surcharge or heavy backing is it necessary to make a retaining wall on a solid foundation more than double the above, or $\frac{1}{2}$ of the height in thickness. Within these limits the engineer must vary the strength in accordance with the conditions affecting the particular case. Outside these limits the structure ceases to be a retaining wall in the ordinary acceptation of the term. A 9-inch brick facing might secure the face of a friable chalk cutting which, if suffered to remain exposed to the action of the weather, would crumble down to a slope of 1 to 1, and a massive bridge pier, with an "ice-breaker" cutwater, might stand firm against an avalanche, but in neither case could the structure be fairly stated to be a retaining wall.

Hundreds of revetments have been built by Royal Engineer officers in accordance with General Fanshawe's rule of some fifty years ago, which was to make the thickness of a rectangular brick wall, retaining ordinary material, 24 per cent. of the height for a batter of $\frac{1}{2}$, 25 per cent for $\frac{1}{8}$, 26 per cent. for $\frac{1}{8}$, 27 per cent. for $\frac{1}{10}$, 28 per cent. for $\frac{1}{12}$, 30 per cent for $\frac{1}{24}$, and 32 per cent. for a vertical wall.

As a result of his own experience the author makes the thickness of retaining walls in ground of an average character equal to $\frac{1}{3}$ of the height from the top of the footings, and if any material is taken out to form a face panel, three-fourths of it are put back in the form of a pilaster. The object of the panel, as of the 1½ inch to the foot batter which he gives to the wall, is not to save material, for this involves loss of weight and grip on the ground, but to effect a better distribution of pressure on the foundation. It may be mentioned that the whole of the walls on the District railway were designed on this basis, and that there has not been a single instance of settlement,

or of coming over or sliding forward. The author has in the present paper analyzed a few dozen experiments, and discussed as many more facts; but an engineer's experience is the outcome not of a few facts, but of the thousands of incidents which force themselves on his attention in carrying out work, and it is this experience, acquired in the construction of works of a somewhat special character, which has convinced the author that the laws governing the lateral pressure of earthwork are not at present satisfactorily formulated.

ELECTRIC POWER.

From "The Engineer."

JUST now nothing save electricity is talked about in scientific circles. During the meeting of the British Association the greatest possible prominence was given to electrical questions and propositions. The success of the electric light, the introduction of the Faure battery with a great flourish of trumpets, and the magnificent display of electrical instruments and machinery at Paris, have all operated to the same end. The daily press has taken the subject up, and journals which were nothing hitherto if not political, now indulge in magnificent rhapsodies concerning the future of electricity. Even eminent engineers carried away by the intoxication of the moment have not hesitated to say that the steam engine is doomed, and that its place will be taken by the electricity engine. In the midst of all this noise and clamor, and blowing of personal trumpets, it is not easy to keep one's head clear, and mistakes may be made which will cause disappointment to many and retard the progress of electrical science. We confidently expect that electricity will prove a potent agent by-and-bye in the hands of the speculator for extracting gold from the pockets of the public, and we write now to warn our readers in time, and to endeavour to clear the air of some of the mists with which it is obscured. There is, no doubt, a great future before electricity; but it is equally certain that electricity can never do many things which the half-informed may be readily made to believe it will do. We propose here to say enough on this point to enlighten our readers without troubling them with perplexing problems and speculations.

No one at this moment knows what electricity is; but for our present purpose we may regard it as a fluid, non-elastic, and without weight, and universally diffused through the universe. To judge by recently-published statements, a large section of the reading public are taught that this fluid is a source of power, and that it may be made to do the work of coal. This is a delusion. So long as electricity remains in what we may call a normal state of repose, it is inert. Before *we can get any work out of electricity a somewhat greater amount of work must be done upon it.* If this fundamental and most important truth be kept in view, it will not be easy to make a grave mistake in estimating the value of any of the numerous schemes for making electricity do work which will ere long be brought before the public. To render our meaning clearer, we may explain that in producing the electric light, for instance, a certain quantity of electricity passes in through one wire to the lamp, and precisely the same quantity passes out through the other wire, and on to the earth or return wire completing the circuit. Not only is the quantity the same, the velocity is also unchanged. But in going through the lamp the current has done something. It has overcome the resistance of carbons, heated them to a dazzling white heat, and so performed work. In doing this, the current of electricity has lost something. Led from the first lamp to a second, it is found powerless—if the first lamp be of sufficient size. What is it that the electricity has lost? It has parted with what electricians term "potential," or the capacity for performing work. What this is precisely, or in what way the presence or absence of potential modifies the nature of the electric current, no one knows; but it is known that this potential can only be conferred on electricity by doing work on the electricity in the first instance. The analogy between electricity and a liquid like water will now be re-

cognized. So long as the water is at rest it is inert. If we pump it up to a height, we confer on it the equivalent of potential. We can let the water fall into the buckets of an overshot wheel. Its velocity leaving the tail race may be identical with that at which it left the supply trough to descend on the wheel. Its quantity will be the same. It will be in all respects unchanged, just as the current of electricity passing through a lamp is unchanged; but it has, nevertheless, lost something. It has parted with its potential—its capacity for doing work—and it becomes once more inert. But the duty which it discharged in turning the mill wheel was somewhat less than the precise equivalent of the work done in pumping it up to a level with the top of the wheel. In the same way the electric current never can do work equal in amount to the work done on it in endowing it with potential.

It will thus be seen that electricity can only be used as a means of transmitting power from one place to another, or for storing power up at one time to be used at a subsequent period; but it cannot be used to originate power in the way coal can be used. It possesses no inherent potential. It is incapable of performing work unless something is done to it first. We have spoken of it as a fluid, but only for sake of illustration. As we have said, no one knows what it is, but the theory which bids fair for acceptance is that it is a mode of motion of the all-pervading ether. Very curious and instructive experiments are now being carried out in Paris by Dr. Bjerkness, of Christiana, in the Norwegian section of the electrical exhibition. This gentleman submerges thin elastic diaphragms in water, and causes them to vibrate, or rather pulsate, by compressed air. He finds that if they pulsate synchronously they attract each other. If the pulsations are not simultaneous, the discs repel each other. From this and other results which he has obtained, it may be argued that the ether plays the part of the water in Dr. Bjerkness' tank, and that when special forms of vibration are set up in bodies they become competent to attract or repel other bodies. This being so, it will be seen that the power of attraction or repulsion of an electrical body depends in the first instance on the motion set up in the body attracted or repulsed, and this motion is, of course, some function of work originally done on the body. We need not pursue this argument further. Among the most scientific investigators of the day it is admitted that the efficiency of electricity as a doer of work, or a producer of action at a distance, must depend for its value on the performance of work in some one way or another on the electricity itself in the first instance. It may be worth while here to dispel a popular delusion. It is held very generally that electricity can be made, as, for instance, by the galvanic battery. There is no reason to believe anything of the kind; but whether it is or is not true that electricity is actually made by the combustion of zinc in a galvanic trough, it is quite certain that this electricity, unless it possesses potential, can do no work, no matter how great its quantity. Of course, it is to be understood that all electric currents possess potential. If they did not their presence would be unknown; but the potential of a current is in all cases the result of work done on electricity, either by the oxidation of zinc, or, in some other way. This is a broad principle, but it is strictly consistent in every respect with the truth. Electricity then is, as we have said, totally different from coal; and it can never become a substitute for it alone. Water power, air power, or what we may, for want of a better phrase, call chemical power, combined with electricity, can be used as a substitute for coal; but electricity cannot of itself be employed to do work. It is true, however, that electricity, on which work has already been done, may be found in nature. Atmospheric electricity, for example, may perhaps yet be utilized. It is by no means inconceivable that the electricity contained in a thunder cloud might be employed to charge a Faure battery; but up to the present no one has contemplated obtaining of power from the clouds, and whether it is or is not practicable to utilize a great natural force in this way does not affect our statement. The use of electricity must be confined to its power of transmitting or storing up energy, and this truth being recognized, it becomes easy to estimate the future prospects of electricity at something like their proper value.

It has been proved to a certain extent that electricity can be used to transmit power to a distance, and that it can be used to store it up. Thus far the man of pure science. The engineer now comes on the stage and asks—Can practical difficulties be got over? Can it be made to pay? In trying to answer these questions we cannot do better than deal with one or two definite proposals which have been recently made. That with which we shall first concern ourselves is that trains should be worked by Faure batteries instead of by steam. It is suggested that each carriage of a train should be provided with a dynamo motor, and that batteries enough should be carried by each to drive the wheels, and so propel the train. Let us see how such a scheme would comply with working conditions. Let us take for example a train fifteen coaches on the Great Northern Railway, running without a stop to Peterborough in one hour and forty minutes. The power required would be about 500 horses indicated. To supply this for 100 minutes, even on the most absurdly favorable hypothesis, no les than 25 tons of Faure batteries would be required. Adding to these the weight of the dynamo motors, and that unavoidably added to the coaches, it will be seen that a weight equal to that of an engine would soon be reached. The only possible saving would be some 28 to 30 tons of tender. In return for this all the passengers would have to change coaches at Peterborough, as the train could not be delayed to replace the expended with fresh batteries. This is out of the question. The Faure batteries must all be carried on one vehicle or engine, which could be changed for another, like a locomotive. Even then no advantage would be gained. As to cost, it is very unlikely that the stationary engines which must be provided to drive the dynamo machines for charging the batteries would be more economical than locomotive engines; and if we allow that the dynamo machine only wasted 10 per cent. of the power of the engine, the Faure batteries 10 per cent of the power of the dynamo machines, and the dynamo motors 10 per cent. of the power of the batteries—all ridiculously favorable assumptions—yet the stationary engines would be handicapped with a difference in net efficiency between themselves and the locomotive—admitting the original efficiency per pound of coal in both to be the same—of some 27 per cent., we think we may relegate this scheme to the realms of oblivion. Another idea is that by putting up turbines and dynamo machines the steam engine might be superseded by water power. Now it so happens that if all the water power of England were quadrupled it would not nearly suffice for our wants. It may be found worth while perhaps to construct steam engines close to coal pits and send out power from these engines by wire; but the question will be asked, which is the cheaper of the two, to send the coal or to send the power? On the answer to this will depend the decision of the mill owners. Another favorite scheme is that embodied in the Siemens' electrical railway. We believe that there is a great future in store for electricity as a worker of tramway traffic; but the traffic on a great line like the Midland or Great Northern Railway could not be carried on by it. As Robert Stephenson said of the atmospheric system, it is flexible enough. The working of points and crossings, and the shunting of trains and wagons, would present unsurmountable difficulties. We have cited proposals enough, we think, to illustrate our meaning. Sir William Armstrong, Sir Frederick Bramwell, Dr. Siemens, Sir W. Thompson, and many others may be excused if they are a little enthusiastic. They are just now overjoyed with success attained; but when the time comes for sober reflection they will, no doubt, see good reason to moderate their views. No one can say, of course, what further discoveries may bring to light; but recent speakers and writers have found in what is known already, materials for sketching out a romance of electricity. It is but romancing to assert that the end of the steam engine is at hand. Wonderful and mystical as electricity is, there are some very hard and dry facts about it, and these facts are all opposed to the theory that it can become man's servant of all work. Ariel-like, electricity may put a girdle round the earth in forty minutes; but it shows no great aptitude for superseding the useful old giant steam, who has toiled for the world so long and to such good purpose.

STRENGTH AND DUCTILITY OF THE COPPER-TIN-ZINC ALLOYS.

By ROBERT H. THURSTON.

(PRESENTED AT THE 13TH ANNUAL CONVENTION, JUNE 17TH, 1881.)

From the Transactions of the American Society of Civil Engineers.*

I.

IN a paper read before the American Society of Civil Engineers a few months since,* the writer gave an account of a method of research which led to the approximate determination of the composition of the strongest possible triple alloy of copper-tin-zinc, and described the properties of alloys made with with more or less accuracy and care by the formula of composition so obtained. In order to exhibit the relation of such metals to the other triple alloys, some of which were already well known compositions, a sketch was given of the relief model used in the identification of the strongest possible metal obtainable by mixture of the three constituents, and a map exhibiting lines of equal tenacity as derived by admeasurements of this model was also introduced as presenting the tenacity of the alloys with greater exactness. This map is here reproduced with some modifications (Fig. 1) which are demanded in further study of the characteristics of these alloys. It was remarked in the earlier paper:

"These alloys were purposely made precisely as the brass founder is accustomed to make them, without other precautions than those observed by every good founder, and without using any of the deoxidizing fluxes—as phosphorus—that would have been experimented with later. The intention was to make this first survey of the field rapidly, inexpensively, and in such a manner as to give a good idea of the best way to pursue the later and much more exact research, while giving the founder a good idea of the nature of the metals that he turns out in every day work.

"The data obtained were consequently exceedingly variable, and the results of this work indicated as one, and not the least valuable, of deductions from it that the same alloy, and especially where the proportion of copper is great, may give very different figures, when tested, according as it is more or less affected by the many circumstances that influence the value of all brass-foundry products.

"Some of the variations in the model are probably due to such accidental circumstances, and quality shown by any individual alloy is representative of a mean which the writer was often compelled to deduce from observations which were quite discrepant. But allowing for all such minor variations, it is evident at a glance that the alloys of maximum strength are grouped, as shown in Figs. 3 and 4, about a point not far from copper=55, zinc=43, tin=2. This point is encircled in the map, Fig. 3, by the line marked 65,000 pounds per square inch (4,570 kilogs. per sq. cm.) tenacity, and is represented on the model by the peak of the mountain seen at the farthest side—the copper zinc side as drawn.

"This is obviously the strongest of all bronzes, and an alloy of this composition, if exactly proportioned, well melted, perfectly fluxed, and so poured as to produce sound and pure metallic alloy, with such prompt cooling as shall prevent liquidation, is the strongest bronze that man can make."

This alloy and the "Tobin alloy"—copper, 58.22; tin, 2.30; zinc, 39.48—were described as good working metals, having toughness and some ductility as well as great strength, and the latter as being capable of great improvement by skillful working either hot or cold, and thus of attaining a tenacity of over 100,000 pounds per square inch (7,311 kilogs. per sq. cm.). Following the inequalities exhibited by the map, the writer called attention to the fact that a line of maximum elevation crosses the field from

* "The Strongest of the Bronzes." Trans. Am. Soc. C. E. No. CCXIV.: Vol. X.; Jan., 1881.

about: copper, 50; zinc, 50; to copper, 85; tin, 15; is included in a band bounded by the formulas: $M=Z+4t=50$, and $M=Z+3t=55$, in which Z is the percentage of zinc present in any triple alloy of that series, and T is the percentage of tin. It was stated that along this maximum line the tenacities of the alloys should be at least $T_m=40,000+500z$ in pounds on the square inch, or $T'_m=2,812+35.15z$ in kilograms on the square centimeter. Thus taking the last line which contains the strongest but least ductile compositions, we find the following tenacities:

The alloy $z=1$, $t=18$ will also contain copper$=100-19=81$ and this alloy cu. 81, zn. 1, sn. 18 should have a tenacity of at least

$T_m=40,000+(500\times1)=40,500$ lbs. per sq. in.

$T'_m=2,812+(35.15\times1)=2,847$ kgs. per sq. cm.

The alloy: cu. 60; zn. 5; sn. 16; should have at least the strength

$T_m=40,000+(500\times5)=42,500$ lbs. per sq. in.

$T'_m=2,812+(35.15\times5)=2,988$ kgs. per sq. cm.

while the alloy z, 50; sn. 2; cu, 48; should give, as a minimum per specification:

$T_m=40,000+(500\times50)=65,000$ lbs. per sq. in.

$T'_m=2,815+(35.15\times50)=4,570$ kgs. per sq. cm.

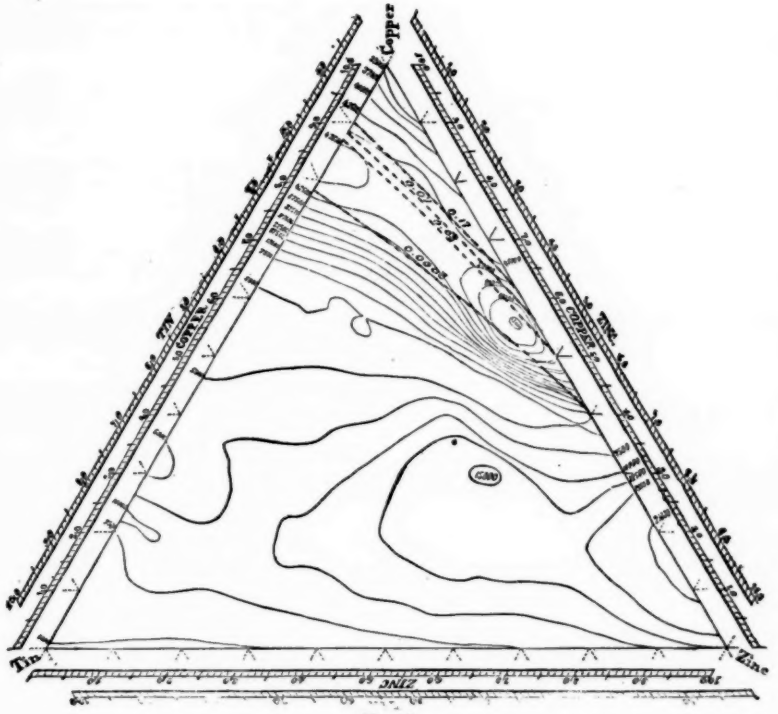


Fig. 1.

"These are rough working formulas that, while often departed from in fact, and while purely empirical, may prove of real value in framing specifications. The formula for the value of T_m fails with alloys containing less than 1 *per cent. tin*, as the strength then rapidly falls to $t=0$."

The writer does not recommend these alloys of maximum tendency for all pur-

poses of construction, as many of them, especially those near the tin sides, are too deficient in ductility and resilience to be safely used where likely to be exposed to severe shock. Where the composition is that of brass, rather than bronze, this line of alloys exhibits more toughness. The alloys—copper, 55; tin, 2; zinc, 43; and copper, 55, tin, 0.5;* zinc, 44.5—were quite excellent in this particular. Tin reduces ductility more rapidly than does zinc. Alloys on the copper side of $z + 4t = 40$ are all tough metals. The copper tin alloys or bronzes, as was stated, should have a tenacity of at least: $T^t = 30{,}000 + 1{,}000t$ where containing not more than 15 per cent. tin, or in metric measure, $T'^t = 2{,}109 + 70.3t$, while the brasses or copper-zinc alloys up to 50 per cent. zinc should have a strength, in British and metric units respectively, of $T^z = 30{,}000 + 500z$ and $T'^z = 2{,}109 + 35.15z$. Thus gun bronze can be given about $30{,}000 + (1{,}000 \times 10) = 40{,}000$ lbs. per square inch if well made. In metric measures, $2{,}109 + 703 = 2{,}812$ kilogs. per sq. cm. Copper, 70; zinc, 30, should have a tenacity of $30{,}000 + (500 \times 30) = 45{,}000$ lbs. on the square inch, or $2{,}109 + (35.15 \times 30) = 3{,}165$ kilogs. per square centimeter. Comparing the last two formulas for tenacity, it is seen that they may be combined, giving equations covering the whole field of copper-tin-zinc alloys useful to the engineer, thus:

$$T_{zt} = 30{,}000 + 1{,}000t + 500z.$$
$$T'_{zt} = 2{,}109 + 70.3t + 35.15z.$$

But it must be understood that this approximate statement of tenacities is a minimum for well-made alloys, and is also applicable only to those containing a larger per centage of copper than those which lie along the maximum line; the alloys to which they apply are, however, the best alloys for general use. Like all such formulations, they must be taken with reserve, and as only representing the cases from the study of which they were derived. For all ordinary purposes of the engineer they may be used without hesitation. Thus we get, for alloys in which $z + 4t < 40$, the following tenacities, representing the minimum that should be accepted. These figures may be greatly exceeded:

* Not 2.5 as printed in earlier paper.

Alloy. Cu.	Zn.	Sn.	Tenacity—Probable Minimum. cm. Lbs. per sq. in.	Kgs. per sq.
100	0	0	30 000	2 109
95	5	0	32 500	2 285
90	10	0	35 000	2 460
85	15	0	37 500	2 636
90	0	10	40 000	2 812
95	0	5	35 000	2 460
97½	0	2½	32 500	2 285
90	5	5	37 500	2 636
85	10	5	40 000	2 812
75	20	5	45 000	3 163
68	30	2	47 000	3 304
64	35	1	48 500	3 410
60	40	0	50 000	3 515

The ductility of these alloys is a subject of quite as much interest to the engineer as their strength; and in this quality the triple alloys are as variable as in every other. Referring again to the map, Fig. 1, it is seen that a closely grouped set of slightly curved and slowly converging lines cross it from about tin $= 25$ to zinc $= 55$, the mean line having an equation, nearly $2.2t + z = 55$. Along this line the alloys have an immense tenacity as exhibited by the fact that some of them, if not nearly all, too hard to be cut by steel tools, and in shaping them only grinding tools—either the emery wheel or grindstone—could be used, and even then with the most unsatisfactory results. Yet such was the brittleness of these metals that no reliable test of their strength could be obtained. Even the slow and cautious handling possible in the autographic machine was quite inadequate to the production of regular and satisfactory determinations. The strain diagrams obtained were perfectly straight, and nearly vertical lines terminating suddenly when the piece snapped without the slightest indication of approach to an elastic limit. They were apparently perfectly elastic up to the point of fracture, but were so nearly destitute of resilience that no use can probably be made of them. Their brittleness was such that they would often break in the mould by their own contraction in cooling, although cast in a straight bar one inch (2.5 c.m.) thick and less than 30 inches (75 c.m.) long. In some cases they were cracked by the heat of the hand, and in several instances were broken at the end by the jar transmitted from a light blow struck at the other end.*

The border lines of this valueless ter-

* Report of United States Board.

ritory is shown on the map by a slightly curved dotted line to which a line having the equation $2.5t+z=55$ is nearly tangent. The alloys lying along this line have nearly equal ductility, extending according to the measurements obtained by the autographic machine, about .03 of one per cent.

Above this line is seen another having nearly the equation $4t+z=50$, which last line is that of equal ductility for alloys exhibiting extensions on the strain diagram of 3 per cent. Still nearer the "pure copper corner" fairly representing alloys containing about $3\frac{1}{2}t+z=48$, and along which the extensions, as per strain diagrams were 7.3 per cent., and another such line extending from the standard gun-metal compositions on the one side to the tough Muntz metal on the other —cu. 90; sn. 10: to cu. 55; zn. 45—of which the equation is nearly $4.5t+z=45$, represents and identifies alloys averaging as cast during this initial research, an extension of 17 per cent. These lines are best seen on the sheet of extensions, Fig. 25. All alloys lying above the line taken here as a boundary line give figures for tenacity that are usually considered good; they all exceed 30,000 pounds per square inch (2,109 kilogs. per sq. cm.).

It is seen that the addition of tin and of zinc to cast copper increases tenacity at least up to a limit marked by the line $3t+z=55$, and that the influence of tin is nearly twice as great as that of zinc,

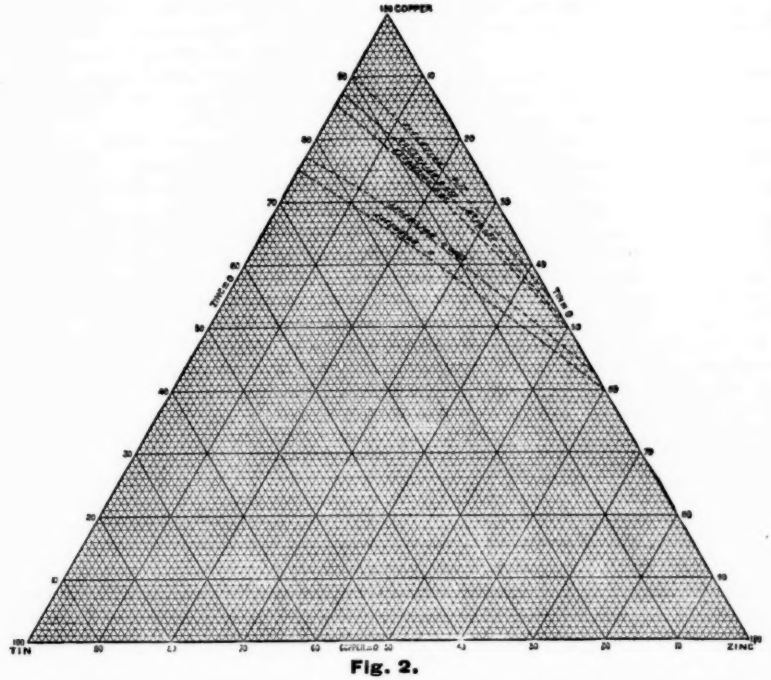


Fig. 2.

while the limit of useful effect is not reached in the latter case until the amount added becomes very much greater than with the former class—the copper tin alloys.

Brasses can be obtained which are stronger than any bronzes, and the ductility of the working compositions of the former class generally greatly exceeds that of the latter.

Triple alloys may be made containing about $4t+z=50$, which exceed in strength any of the double alloys and composi-

tions approaching copper, 55 tin, 2; zinc, 43; as the maximum of maximums, may be made, which are of extraordinary value for purposes demanding great strength, combined with the peculiar advantages offered by brass or bronze. The addition of one-half per cent. tin to Muntz metal confers vastly increased strength. So sensitive is zinc in the presence of tin that M. Bischof states that he can detect the addition of one part of tin in ten millions of pure zinc.

The range of useful introduction of tin is very much more restricted than with zinc; alloys containing 12 to 15 per per cent. are so hard and brittle as to but rarely find application in the arts, while brass, containing 40 per cent. zinc, is about the toughest and most generally useful of all the copper-zinc "mixtures." The moduli of elasticity of these alloys are remarkably uniform, more than one-half of all those here described, ranging closely up to fourteen millions, or one-half that of well-made steel wire, such as is used in the New York and Brooklyn Bridge. The moduli gradually and slowly increase from the beginning of the test to the elastic limit.

The fracture of these alloys is always illustrative of their special characteristics. Those broken by tortion in the autographic testing machine were, if brittle, more or less conoidal at one side of the break; ductile alloys yield in similar circumstances by shearing in a plane at right angles to the axis of the test piece; the former resemble cast iron and the latter have the fracture of wrought iron. Every shade of gradation in this respect is exhibited by an observable modification of the surface of fracture, varying from that characteristic of extreme rigidity and brittleness, through an interesting variety of intermediate and compound forms to that seen in fracture of the most ductile metals.

Notwithstanding the fact that the demise of the United States Board left this investigation in a sadly incomplete state, it will probably become evident to those who may obtain the report that at least a beginning has been made and the field fairly reconnoitered, leaving to some future investigator a prospect of immediate valuable recompense for such additionable labor as he may be able to expend in a detailed reconnoissance or an extended survey. While studying the figures here given, and especially those reported by the United States Board, it must not be forgotten that the tenacities and even the ductilities given are far within the best attainable figures where they relate to the most valuable working bronzes and brasses. These figures represent the result of ordinary, every day founders' work, and metals rich in copper made, as were these, with no greater precaution against oxidation and liquidation than is usual in brass foundries, may be vastly improved by the special treatment suggested in the preceding paper, by using pure ingot metals, fluxing carefully, as with phosphorus or manganese, casting in chills, rapid cooling, and finally rolling or otherwise compressing either hot or cold.

Unannealed copper wire is reported by Baudrimont* as having a tenacity of about 45,000 pounds per square inch (3,163 kilogs. per sq. c. m.), and Kirkaldy reports 28.2 tons per square inch (63,168 pounds per square inch; 4,440 kilogs. per square c. m.), the wires having diameters of 0.0177 and 0.064 inches (0.044 and 0.165 c, m.) respectively.

It can hardly be doubted that a way may yet be found to secure equal purity, homogeneousness, and density in cast copper, and such metal should then possess equal tenacity and toughness with rolled metal. Gun-bronze, which ordinarily has a tenacity of about 35,000 pounds per square inch (2,460 kilogs. per sq. c. m.) has been made at the Washington Navy Yard, by skillful mixture, melting and pouring, to attain a tenacity of above 60,000 pounds (4,218 kilogs.).

The effect of thorough fluxing with deoxidizing substances is so important that no founder can safely neglect it.

Bronzes fluxed with phosphorus, arsenic, and manganese have been given fifty per cent. higher tenacity than the ordinary unfluxed alloy, and the addition of a little iron, as in the so-called "sterro-metal" of the Baron de Rosthorn, and in Parson's "Manganese Bronze," has still further strengthened the copper-tin-zinc alloys.

Attention has been called in the preceding paper to the value of gold rolling, and other mechanical treatment of the

* Annales de Chimie, 1850.

"maximum alloys," examined by the writer, and one case was cited in which the tenacity was increased from 66,500 pounds per square inch (4,575 kilogs. per sq. c. m.) by rolling hot to 79,000 pounds (5,553 kilogs.), and by cold rolling to 104,000 pounds (7,311 kilogs.). Dr. Anderson, the Superintendent of Machinery of the British War Department, when associated with the writer at Vienna, 1873, referred to experiments at Woolwich, showing an increase of strength of sterro-metal by forging to the extent of 25 per cent,, and by drawing cold of 40 per cent. Brass, containing copper, 62 to 70; zinc, 38 to 30, attains a strength in the wire mill of 90,000 pounds per square inch, and sometimes of 100,000 (6,327 to 7,030 kilogs. per sq. c.m.), and the time will come, we may hope, and fairly expect, when these alloys may be made equally tenacious in the casting. The writer has no doubt that the methods indicated by him as those best adapted to secure dense, strong and tough metal will yet be found capable of yielding alloys, of more than double the strength shown here to be fairly representative of what is now ordinary brass founder's work. It should be possible to secure copper-tin-zinc alloys having tenacities represented by:

$$T''_{mm} = 60{,}000t + 1{,}000t + 500$$
$$T'_{mm} = 4{,}218 + 70.3t + 35.15_z,$$

throughout that area on the map representing the more useful alloys, say from copper, 100; to $4t + z = 50$.

Manufacturers of special bronzes are already approaching this degree of excellence. The appended tables illustrate the method of investigation adopted in studying the triple alloys, and exhibit the behavior under test of the sample of "Gun Bronze, No. 1,252," of which autographic strain diagrams were given in the preceding paper on "The strongest of Bronzes." This bar was made to order for the writer to determine the value of an organic material proposed as a flux; it had no special value, however, and the record is here given in illustration only.

No. 585 was a sample of brass in which 20 per cent. zinc, takes the place of 10 per. cent. tin in bar No. 1,252. This piece had very nearly the same tenacity, double the ductility, a slightly lower modulus of elasticity, and far less transverse strength—probably in consequence of less hardness. Adding zinc until the proportion becomes 37.5 per cent., as in No. 609, the tenacity rises to 48,760 pounds per square inch (3,428 kilogs. per sq. c.m.), the modulus of elasticity is increased to fifteen millions, and the transverse strength is doubled.

No. 856 is an alloy of very nearly the same composition, to which 23 per cent. tin has been added. It is seen that this change has produced an enormous increase of strength, bringing the tenacity up to 67,600 pounds per square inch (4,752 kilogs. per sq. c.m.), and while decreasing the modulus of elasticity has greatly increased the transverse strength. This bar was referred to in the preceding paper, and the records of its test are here also appended as exhibiting the behavior of this alloy during the progress of the tests. The extensions given are measured in a length of five inches; they are, therefore, to be multiplied by 20 to obtain the per centage of extension. This bar is very strong, but deficient in ductility.

The transverse tests exhibits these characteristics with equal distinctness. The load carried was nearly a ton and a half, and the deflection but 2 inches (5 c. m.); the modulus of elasticity slowly but steadily decreased from the start. Note (a) calls attention to a phenomenon more than once noticed, of an increased effort to decrease flexure after a short interval of rest under light load, having received set under heavier stress. The remainder of the record illustrates the usual gradual increase of set under heavy loads. Somewhat similar behavior was noticed in the transverse test of No. 1,001, an alloy of which the strain diagrams from the autographic machine were given in the paper on the strongest of the bronzes. The note appended to the record calls attention to the singular recovery from set, which here amounts to 0.004 inches (0.01 cm.) in about 16 hours.

The last set of records here given are those of a pure bar copper, made and tested for the U. S. Board,* and show well what may be expected of good copper castings, even without special fluxing

* See Report of 1878.

or other unusual treatment. This bar was strong, carrying nearly 30,000 pounds per square inch (21.09 kilogs. per sq. cm.) in tension, but it lacked ductility, a consequence of the presence of copper oxide.

In the working of copper in the foundry the melter is sure to meet with difficulty from the formation of either the oxide or carbide. Could he secure immunity from the danger of combination with one or the other of these elements, he would find innumerable uses for cast copper. One of the discoveries to be looked for, and to be hoped for, is a method of securing pure cast copper. The stronger affinities of the metal, when molten, make this problem a more difficult one than that of obtaining sound steel castings. The transverse strength of the metal seemed to have been less reduced by the presence of the oxide than was its tenacity. The fact that the bar could be broken at all in the transverse testing machine is evidence of reduction of ductility due to this cause. The record of the compression test seems to indicate that form of resistance due to the presence of oxide.

The general character and the method of variation of strength and ducility of the alloys of copper, tin, and zinc are so well exhibited by the illustrations which have been presented in these papers, that it is the hope of the writer that no difficulty will be met with by the engineer in the endeavor to select the alloy best adapted to any specific purpose where such an adaptation is determined by physical qualities alone. Caution must be used in selecting alloys where great strength is demanded, since a slight change of composition by the addition of tin or zinc may make a serious change in the direction of lessened ductility and toughness. The engineer will rarely use those lying on the tin and zinc side of the line of alloys having 0.07 (7 per cent.) ductility, as on Figs. 1 and 2. Extraordinary care must also be taken in making the strongest of these alloys.

Alloys to be hammered or rolled will be found more difficult to work as the per centage of tin is increased, and the minutest addition of tin to the brasses usually rolled is found to sensibly decrease their manageability.

RECORDS OF TESTS MADE AT THE STEVENS INSTITUTE OF TECHNOLOGY.

Material Bronze—Copper, 89,974 per cent.; Tin, 9,997 per cent.; Flux, etc., 0,029 per cent.

I. RECORD ACCOMPANYING AUTOGRAPHIC STRAIN DIAGRAMS. GUN BRONZE.

Lab. No.	Size for Estimates. Length L	Size for Estimates. Diameter H	Stresses in Torsion. foot-pounds. Proof M	Stresses in Torsion. foot-pounds. Ultimate M	Elasticity.	Elasticity Resilience.	Ratio of Extension. Proof.	Ratio of Extension. Maximum.	Homogeneousness as to Structure.	Homogeneousness as to Strain.	Stiffness.	Resilience W	Modulus of Resistance (A) Torsion Elastic. $A^E = \frac{M'L}{H\theta_E}$	Modulus of Resistance (A) Torsion Proof $A' = \frac{M'}{H_s}$	Modulus of Resistance (A) Torsion Ultimate $A = \frac{M}{H_s}$	Angle. θ_E	Angle. θ_R
1252B	1″	.625″	49.03	99.83	.00717	0.38	.000013	.04787	Ex.	Ex.	54.5	84.60	571.2	200.94	409.1	0.9°	57.2
1252B$_2$	"	"	71.71	127.05	.00776	1.55	.000089	.07554	"	"	29.9	138.60	313.3	293.9	520.7	2.4°	72.6

2. Records of Tests by Tension.

Copper....89.974%

Tin..... 9.997% Gun Bronze.

Flux, etc.. 0.029% Lab. No. 1252A[2]

Dimensions. Original and Final.		Stresses.		Proof Load per Square Inch Area of	Breaking Load per Square Inch.	Extension.		Modulus of Elasticity. E	Modulus of Resilience. W
Length. L, L'	Diameter. H, H'	Proof.	Ultimate.	Original Section P	Original Section T	Actual	% of Original Length.		
5"	.798"	150	.....	300	.....	.....	.....	11 467 763	
.....	.....	1000	.....	2000	.....	.0008	.016%		
.....	.....	2000	.....	4000	.....	.0016	.03		
.....	.....	3000	.....	6000	.....	.0024	.05		
.....	.....	4000	.....	8000	.....	.0056	.07		
Elastic	Limit.	5000	.....	10000	.....	.0047	.09	.....	0.98
.....	.....	6000	.....	12000	.....	.0063	.13		
.....	.....	7000	.....	14000	....	.0080	.16		
... .	.....	8000	.....	16000	.....	.0112	.22		
.....	.....	9000	.....	18000	.....	.0166	.33		
.....	.....	10000	.....	20000	.....	.0263	0.53		
.....	.....	11000	.....	22000	.....	.0428	.86		
.....	.....	12000	.....	24000	.....	.0675	1.35		
.....	.....	13000	... ...	26000	.....	.1009	2.045		
.....	.....	15000	.....	30000	.....	.2069	4.14		
.....	.....	.....	15500	.....	31000	.23	4.6	.....	242

3. Records of Tests by Compression.

Copper.... 89.974%

Tin..... 9.997% GUN BRONZE.

Flux, &c.. 0.029% Lab. No. 1252C_2.

Dimensions. Original and Final.		Stresses.	Proof load per square inch area of	Breaking load per square inch.	Compression.		Resilience. W
Length. L, L′	Diameter H, H′	Proof.	Original section. P.	Original section. T.	Actual.	Per ct. of original length.	Foot. Pounds
2″	.625	150					
		1000			0.0019″	0.09%	
		2000			.0032	.16	
		3000			.0033	.16	
		4000			.0040	.20	
		5000			.0048	.24	
		6000			.0076	.38	
Elastic limit.		7000	22816		.0117	.58	6.825
		8000			.0227	1.13	
		9000			.0385	1.92	
		10000			.0609	3.04	
		11000			.0867	4.33	
		12000			.1163	5 81	
		13000			.1494	7.47	
		14000			.1794	8.97	
		15000			.2110	10.55	
		16000			.2402	12.01	
		17000			.2678	13.39	
		18000			.2989	14.94	
		19000			.3229	16.14	
		20000			.03599	17.99	
		21000			.3904	19.52	
		22000			.4164	20.82	
		23000			.4478	22.39	
		24000			.4870	24.35	
		25000			.5092	25.46	
		26000			.5409	27.04	
		27000			.5706	28.53	
		28000			.5999	29.99	
		29000			.6235	31.17	
		30000			.6460	32.30	
		31000			.6694	33.47	
		32000			.6904	34.52	
		33000			.7125	35.62	
		34000			.7311	36.55	
		35000			.7517	37.58	
		36000			.7726	38.63	
		37000			.7914	39.57	
	.769	38000		123860	.8115	40.57	1.480

4. Records of Tests by Transverse Stress.

Copper.... 89.974%
Tin..... 9.997%
Flux, &c... 0.029%

Gun Bronze.

Lab. No. 1352.

Dimensions Original and Final.		
Length.	Breadth.	Depth.
l. l'.	b. b'.	d. d'.
22″	1.020″	0.97″

	Proof stresses.		Deflection.	Breaking load.		Modulus of elasticity.	Modulus. of resilience.
	Absolute. P_1	Modulus. $R_1=\frac{3P_1l}{2bd_2}$	Absolute. δ	Absolute. P	Modulus. $R=\frac{3Pl}{2bd_2}$	$E=\frac{Pl_3}{48\delta 1}$	W Ft. lbs.
—	3	.....	.....	.....	.....	.....	
	10	.....	0.0016″			13,487,264	
	20	.....	.0036				
	40	.....	.0084				
	80	.....	.0179				
	120	.....	.0257				
	160	.....	.0344				
	200	.....	.0429				
	3	.....	.0012				
	240	.....	.0502				
	280	.....	.0581				
	320	.....	.0669				
	360	.....	.0761				
	400	.....	.0845				
	3	.....	.0034				
	440	.....	.0929				
	480	.....	.1015				
	520	.....	.1102				
	560	.....	.1192				
	600	.....	.1277				
	3	.....	0.0054				
	640	.....	.1364				
Elastic limit.	680	23,375	.1463	.....	.....	.....	4.145
	720	.....	.1594				
	760	.....	.1717				
	800	.....	.1879				
	3	.....	.0276				
	840	.....	.2039				
	880	.....	.2219				
	920	.....	.2475				
	960	.....	.2832				
	1000	.....	.3310				
	3	.....	.1248				
	1040	.....	.3841				
	1080	.....	.4426				
	1120	.....	.5359				
	1160	.....	.6492				
	1200	.....	.7774				
	3	.....	.5114				
	1240	.....	.9043				
	1280	.....	1.027				
	1320	.....	1.1998				
	1360	.....	1.407				
	1400	.....	1.694				
	3	.....	1.2008				
	1440	.....	1.835				
	1480	.....	2.020				
	1520	.....	2.237				
	1560	.....	2.553				
	1600	.....	3.1108				
	3	.....	2.462				
	1640	.....	3.358	1640	56,375	.....	327,5

EXPERIMENTS ON THE OTTO GAS ENGINE.

By Prof. FRANCESCO SINIGAGLIA.

From "L'Ingegneria civile e le Arti Industriali" for Abstracts of Institution of Civil Engineers.

This paper consists in a mathematical investigation of a large number of indicator diagrams, sixteen of which are reproduced for reference. The diagrams are of two kinds; the first refer to the results obtained from the explosion of the mixture of gas and ordinary air, which may be called diagrams of motor power; the second kind are obtained when the valve which admits the gas is closed, and are called diagrams of resistance. The various stages of pressure are clearly represented by the diagrams, from which it appears that at the end of the motor stroke the internal pressure in the cylinder is less than that of the atmosphere. The highest pressure figured on any of the diagrams is 7 atmospheres. The author remarks that the machine is liable to become dirty internally; and should be frequently overhauled and cleaned. The editor of the journal adds in a note, that if oil of a good quality is employed for lubrication it is sufficient for the valve to be cleaned every twelve or fifteen days, and the interior of the cylinder once a month. From a great number of diagrams the author deduces the following formulæ:—

Let A = the area of piston in square centimeters, which = 103.81.

C = the length of stroke in meters, which = 0.2315.

p_m = the mean pressure, taken from the diagrams.

n = the number of strokes per second.

Then the work is thus represented:

$$\frac{np_mAC}{2\times 60} \text{ kilogrammeters per second.}$$

The author proceeds to give formulæ, too complicated for abstract, for the resistance of the machines, for proportion between the gas consumed and the air admitted, for the heat produced by the combustion, for the heat conducted away by the products of combustion, for the relation between these two last-mentioned quantities, for the relation between the heat developed and that absorbed by the water, for the heat lost by vaporization of water and by radiation, and for the proportion between the work indicated by the diagrams, and that actually utilized as motor power. He finally arrives at the result that the indicated work, where $n=170$, and $p_m=1.590$, amounts to 0.722 HP.; the friction to 0.283 HP.; and the effective work to 0.439 HP., or 60 per cent. of useful effect.

The consumption of gas per HP. indicated per hour he gives as,

$$\frac{0.960 \text{ cubic meter}}{0.734 \text{ HP}} = 1.307 \text{ cubic meter,}$$

and per HP. effective as

$$\frac{0.960 \text{ cubic meter}}{0.451 \text{ HP.}} = 2.128 \text{ cubic meters.}$$

The editor adds a note to the effect that a consumption of 1.200 cubic meters per HP. per hour is the highest that has yet been determined from numerous experiments conducted by very able engineers for any of these engines.

The author concludes that the diagrams derived from his practice differ from those drawn according to theory, those drawn according to Boyle's law of compression being 20 per cent. in excess of, and those drawn according to the adiabatic theory being 20 per cent. less than those which he has obtained. The cost of gas, at the price of 32 centissimi per cubic meter (without allowing anything for the hire of meter) is 3.60 lire (2*s.* 10½*d.*) for a day of ten hours, which he states to be much higher than that of a steam engine of equal power, that is to say, of 0.451 effective HP.

A COMPOUND INTEREST CURVE.

By FRANK D. Y. CARPENTER, C.E.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

ALL interest is the result of growth. If this growth is uniform, the increase during any period of time being a constant percentage of some fixed capital, the result is simple interest. If it is constantly increasing in rapidity, its amount during any differential of time being a constant percentage of the accumulated principal and increment at the beginning of this period, the result is compound interest.

As far as organic growth can be said to obey any regular law, a human being or a tree increases in stature by simple interest, but in girth by compound interest, since the layer of fiber or tissue added to the trunk, during any interval, must be sufficient to inclose all preceding envelopes, and therefore be larger than the largest of them. The depth of snow during a storm increases by simple interest; the size of a ball of the same rolled along the ground by the schoolboy, or dashing down the mountain side until it becomes an avalanche, grows by compound interest. Supposing the nations of the world to remain in a normal condition as regards health, peace, government and prosperity, and our supply of vacant land to continue unstinted, our population will increase through immigration by simple interest, and through reproduction by compound interest.

This and any other growth may be represented graphically by the line which would be described by the culminating point of the growing substance and referred to rectangular axes of co-ordinates. That component of its progress which lies along the axis of abscissas will be a measure of the time considered, while the intercepted portion of the axis of ordinates will represent the amount of principal and interest at any given date. Thus time and matter are given in terms of the same linear measurement. By assigning to them arbitrary values at will, such as one year to the inch for one axis, and a thousand dollars, or one hundred feet, or one million people to the inch for the other, the equation for the line of growth by simple interest takes the form of

$$y = ax + b,$$

of which b is the principal and ax is the accumulated interest. But the above is the equation of the straight line, which is, therefore, the representative of growth by simple interest, a fact which is self-evident when we consider that in this process equal increments to x, the time, are always accompanied by equal increments to y, the amount. To draw this line it is only necessary to find two points in the same—that is, the amount of principal and interest at any two dates, and they will determine its position.

In all of the practical operations into which the computation of compound interest enters, the interest is compounded with the principal at stated intervals, the same rate of interest being applied to the increased principal at the end of each of these periods of time. Thus for equal increments to x, the time, there are constantly increasing increments to y, the amount, and the course of the culminating point is a broken line, of which the sections make larger and larger angles with the axis of abscissas as the time increases. In order to draw this broken line it is necessary to compute the ordinate, that is, the amount, as often as the interest is compounded with the principal, which, in financial transactions, may be annually, semi-annually or quarterly.

Natural growth, however, does not proceed in this broken and angular manner. In natural growth the interest is compounded and a new principal is assumed at the end of each infinitesimal of time, and the broken line melts into a curve. To complete all of the ordinates of this line, as of any other curve, would be literally an infinite work. Therefore, to describe this curve of growth, or compound-interest curve, we first find a convenient number of points lying therein, and through them trace the approximate course of the line desired.

But as natural growth does not proceed in compliance with the terms of any human contract, and we have no means of knowing in advance what will be its rate of increase for each year, day, minute or infinitesimal of time, and what will be the successive values of the growing quantity at the expiration of these periods, we can only treat this subject retrospectively, and interpolate between two values of the growing substance as found by measurement at the beginning and end of a completed cycle of time. To effect this interpolation it has usually been the custom to assume that successive values have constituted a series of which the second differences were equal and the third differences were, therefore, zero; but this is never true for any growth by compound interest, in which, however continued, no order of differences will disappear. It is now desired to find some method of interpolation which will give correct results, assuming that the growth has been in conformity with some regular law of compound interest, this being the only theory admissible.

Let B = the first principal, the measured value at the beginning of the cycle.

Let A = the final amount, the measured value at the end of the cycle considered.

Let n = the number of equal periods into which the cycle is divided, at the end of each of which the interest is compounded with the principal.

Let p = the number of these periods, at the end of which it is desired to find the amount.

Let y = the desired amount.

Let x = the rate per cent. of gain for each period considered.

As in each of these periods the principal, as it was at the beginning of this interval, is increased by a certain fraction of itself, we have the following continued proportion: the first principal is to the second or first amount, as this second is to the third, as the third is to the fourth, etc. That is,

$$B : B+\frac{x}{100}B :: B\left(1+\frac{x}{100}\right) : B\left(1+\frac{x}{100}\right)^2 ::$$

. . . . . .

$$:: B\left(1+\frac{x}{100}\right)^{n-1} : B\left(1+\frac{x}{100}\right)^n$$

But $$B\left(1+\frac{x}{100}\right)^n = A$$

whence $$\left(1+\frac{x}{100}\right)^n = \frac{A}{B}$$

and $$1+\frac{x}{100} = \left(\frac{A}{B}\right)^{\frac{1}{n}} \quad . \quad . \quad . \quad (1)$$

In the same manner it may be demonstrated that

$$B\left(1+\frac{x}{100}\right)^p = y,$$

$$\left(1+\frac{x}{100}\right)^p = \frac{y}{B},$$

and $$1+\frac{x}{100} = \left(\frac{y}{B}\right)^{\frac{1}{p}}.$$

Therefore,

$$\left(\frac{y}{B}\right)^{\frac{1}{p}} = \left(\frac{A}{B}\right)^{\frac{1}{n}},$$

$$\frac{y}{B} = \left(\frac{A}{B}\right)^{\frac{p}{n}},$$

$$\log.\left(\frac{y}{B}\right) = \frac{p}{n}.\log.\left(\frac{A}{B}\right)$$

$$\log. y - \log. B = \frac{p}{n}.\log.\left(\frac{A}{B}\right)$$

$$\log. y = \log. B + \frac{p}{n}.\log.\left(\frac{A}{B}\right) \quad . \quad . \quad (2)$$

Whence y is readily found.

A convenient subject to which to apply this formula is the increase of the population of the United States for the cycle of ten years between the census of 1870 and that of 1880. To avoid too great complication in the problem it will be necessary to neglect the irregularity of increase resulting from varying immigration and other abnormal influences, and to assume that our gain in numbers has been a steady growth by compound interest.

The population of the United States, June 1, 1870, was 38,558,371; on June 1, 1880, 50,152,866; increase, 11,594,495. Theoretically there have been 11,594,495 equal increments to the population, added at intervals of a little less than half a minute, but which intervals have been constantly growing smaller as the population has increased. The interest has been compounded with the principal 11,594,495 times, and the line of growth, being broken by so great a number of sections and angles, is practically a curve and will be treated as such. Since it is manifestly impossible to compute the total 11,594,595 ordinates which deter-

mine the position of this broken line, a smaller number will have to suffice. Let us derive the values of the ordinates of the intervening curve of growth for each year of the decade between 1870 and 1880. Then, the curve having been described with their aid, any intermediate value of the ordinate may be taken directly from the drawing by erecting a perpendicular at that point of the axis of abscissas corresponding to any desired date in the decade. Or the value of this ordinate, or population, may be computed more accurately, as will hereafter be illustrated.

To find, then, for example, the population of the United States, June 1, 1873:

Here B=38,558,371, the initial population of the cycle.

A=50,152,866, the final population.

n=10, the number of equal periods into which the cycle is divided.

p=3, the number of these periods embraced.

Supplying these values in equation (2), we have

$$\log. y = 7.6203718,$$
$$y = 41,722,640.$$

In this manner the following table has been prepared, showing the theoretical increase of the population of the United States from June 1, 1870, to June 1, 1880:

Date.	Population.	Remarks.
June 1, 1870....	38,558,371	Enumerated.
" 1, 1871....	39,585,530	Computed.
" 1, 1872....	40,640,040	"
" 1, 1873....	41,722,640	"
" 1, 1874....	42,834,090	"
" 1, 1875.....	43,975,140	"
" 1, 1876....	45,146,580	"
" 1, 1877....	46,349,240	"
" 1, 1878....	47,583,930	"
" 1, 1879....	48,851,510	"
" 1, 1880....	50,152,866	Enumerated.

To find, by the formula, the population for the intermediate date of April 1, 1873:

A=50,152,866,
B=38,558,371,

n=120, the number of months in the cycle of ten years.

p=34, the number of months from June 1, 1870, to April 1, 1873.

Whence y=41,540,220.

To find the population for the intermediate date of July 4, 1876:

A=50,152,866,
B=38,558,371.

n=3653, the number of days in the cycle of ten years.

p=2226, the number of days from June 1, 1870, to July 4, 1876.

Whence y=45,257,830.

By the aid of this formula the statistician, with the necessary time and inclination, can construct a curved line which will represent the growth of our population from the date of the first census in 1790, to the last in 1880. The enumerated values for the several decades will furnish ordinates which the curve of growth must imperatively touch. Between these positive values the formula will give intermediate ordinates which will locate the intervening theoretical curve of increase. This ideal curve may then be used as a guide line, in the neighborhood of which the historian, having in view the vicissitudes which have influenced the growth of population, may draw an approximately true line of increase. For instance, this curve will not depart widely from the horizontal during the period of our civil war, when death almost kept pace with birth; it will receive an upward impulse in those years in which our immigration is greatest, and also in the spring-time of each year, owing to the excessive influx of immigrants at that time; and it will ascend less rapidly than the normal curve in those seasons in which mortality is greatest, and especially in those years when we have been visited by pestilence. In short, it will be the barometric curve of the nation's prosperity.

The decennial rate of increase of our population for the last decade has been $30\frac{6998}{100,000}$ per cent.

From equation (1),

$$1+\frac{x}{100}=\left(\frac{A}{B}\right)^{\frac{1}{n}},$$

and its sequel,

$$\log.\left(1+\frac{x}{100}\right)=\frac{1}{n}.\log.\left(\frac{A}{B}\right),$$

we derive the annual rate of increase, x, which is $2\frac{66388}{100000}$ or about $2\frac{2}{3}$ per cent.

If any one wishes to indulge in the precarious pastime of guessing at the future, and if he is satisfied to predict a corre-

sponding rate of interest for the present decade, he will find the annual series to run as follows:

Date.	Population.	Remarks.
June 1, 1880....	50,152,866	Enumerated.
" 1, 1881....	51,488,880	Computed.
" 1, 1882....	52,860,480	"
" 1, 1883....	54,268,630	"
" 1, 1884....	55,714,280	"
" 1, 1885....	57,198,450	"
" 1, 1886....	58,722,150	"
" 1, 1887....	60,286,440	"
" 1, 1888....	61,892,400	"
" 1, 1889....	63,541,160	"
" 1, 1890....	65,233,820	"

This forecasting of the population, however, does not rise above the dignity of scientific fortune-telling, and it rarely fails to bring the fortune-teller to grief. Instead of an increase of but 30 per cent. in this decade, the present tide of prosperity may continue and carry us forward $35\frac{6}{10}$ per cent., as in the ten years from 1850 to 1860, and give us a total of 68,000,000 in 1890; or some unexpected evil may befall us and retard our growth to $22\frac{6}{10}$ per cent., as in the decade of the rebellion, in which case our population at the next enumeration will be but 61,500,000. Time alone can tell.

THE SANITARY AND CONSTRUCTIVE SUPERVISION OF DWELLINGS.*

By LEWIS ANGELL, M. Inst. C. E.

THAT "An Englishman's house is his castle" is a fondly-cherished tradition. Be the Castle one of Indolence, Ignorance, Dirt, or Disease, who dare invade it? But a castle means isolation, a separation of neighbors by walls and entrenchments: and so long as the lord thereof and his retainers remain within the keep, their doings do not concern the outer world. But if the garrison sallies forth, committing devastation, are not the attacked justified in invading the castle? "Self-preservation is the first law of nature;" and if sanitary science, unknown to our mediæval ancestors, has taught the modern Englishman that the safety of his own well-ordered castle is dependent upon his neighbor's being also set in order, surely the most radical opponent of paternal government will concede that freedom must be qualified by the moral and physical rights of our neighbor. One of the earliest applications of this principle of compulsory sanitation was in the Vaccination Acts. Legislation also prohibits the exposure of infected persons and clothing. More recently the principle has been extended by local Acts requiring that the various kinds of infectious disease shall be reported to the medical officer of health. The extension of sanitary supervision to dwellings is therefore not only in harmony with established principles, and precedents, but is, in fact, a demand which has found expression in the recent establishment of societies in London and Edinburgh for sanitary inspection on co-operative principles. The latest development of the movement is the "London Sanitary Company," an association of eminent sanitarians who propose to combine philanthropic principles (limited) with the business of a big plumber. The company contemplates, as a "moderate estimate," an annual receipt of 10,000 guineas from 10,000 houses, independently of "entrance fees" and the profits from plumbing. The skilled advice of the highest medical and sanitary authorities will be secured, surveys and reports made by "an efficient inspecting satff acting under the direction of the company's engineers." The company will put dwelling houses in a perfectly sanitary condition, filter water, cleanse cisterns, prevent boiler explosions—in fact, sanitary repairs of all kinds will be "neatly executed at the shortest notice." A dividend of 20 per cent. is suggested by the prospectus, and $7\frac{1}{2}$ per cent. guaranteed by the plumber whose business has been acquired by the company as a "going concern," and whose services the com-

*Read before the Association of Municipal and Sanitary Engineers and Surveyors at Birmingham, on July 8.

pany have been fortunate enough to secure as "managing director." It is to be regretted that the aspirations of the company should stop short in so great a work. Surely ratepayers would not object if the company would also take over local boards as a "going concern," and guarantee a dividend, however small. A guinea rate per house per annum, officially levied by the sanitary authority, would very much more than maintain an efficient and responsible staff of sanitary inspectors, who would extend their protection to the poor as well as to the well-to-do subscribing shareholders, whom alone the "Sanitary Company" proposes to benefit. The fact of the existence of such societies, be they due to philanthropy or stock jobbing, raises a great question: Is such sanitary supervision necessary? and, if this be granted, by whom should it be conducted? That supervision is necessary will be admitted by all who, like the members of this association, have had any official experience. Thousands, probably hundreds of thousands, of houses are annually put together, we cannot say built, in such manner as to be dangerous to the lives of the occupants. Not only is stability disregarded, but every essential principle of sanitation ignored; the water pipes, the drain pipes, the very site frequently a huge dust bin, form a combination of contaminating influences which lower vitality and endanger life. This result is due as much to ignorance as to carelessness—a concourse of fortuitous evils rather than a conspiracy, although one regrets to have to add, as the result of official experience, that in too many instances it is also the result of the most wilful and wicked cupidity. As a practical illustration I may be allowed to quote my own official experience. For more than fourteen years past I have had the supervision of by far the largest district in the country governed by a local board; all other places of its size, and very many smaller, have municipal corporations. I refer to the district of West Ham, in Essex, which forms part of the the "outer ring" of "Greater London." It includes nearly 130,000 inhabitants, having more than doubled during the last ten years. Some 14,000 houses have been put up during my term of office, and at present they are increasing at the rate of about 2,300 per annum, equivalent to a new street of nearly 200 houses per month. These buildings require supervision. Being "over the border," we have no building fees as in the metropolis, a fact which induces the speculating builders to come over. If only a guinea were charged on each building—only *one* guinea, not the *annual* guinea invited by the "sanitary company"—my board would, independently of the rates, derive an income which would enable them to provide a qualified and responsible supervising staff not only to enforce the proper construction of new buildings, but to discover defects in old ones. The Local Government Board recently issued a series of model by-laws for buildings, involving very much detail; the advantage of their adoption was manifest, but adoption and observance are very different matters. I would have gladly urged their adoption by my Board had I not also felt there was no chance of their general observance over a district of 7¼ square miles with the staff I had at my disposal. The matter was so represented to the Local Government Board, and the imposition of building fees urged so as to provide a staff to carry out the by-laws; the reply was a courteous promise of consideration, but hoping, in the meantime, their "model" would be adopted. To this day the Local Government Board has done nothing to assist he officers, neither has my Board adopted the by-laws, for I hold it is bad policy to enact laws which cannot be enforced, which will be observed only by respectable and entirely disregarded by "jerry" builders. The infliction of penalties here and wholesale escape elsewhere is suggestive of official favoritism, and I maintain that we had better be without such minute laws than to bring them and the officers into disrepute and contempt by their habitual infraction. It is not, therefore, out of any want of appreciation or spirit of opposition that West Ham has not adopted the model laws of the Local Government Board. The moment the means are provided to maintain a staff for their observance, their adoption is certain. And, here in passing, I cannot refrain from giving public expression to a feeling present in the minds of every member of this asso-

ciation. As public officers, the Local Government Board impose their obligations upon us, they favor us with their criticisms, but in no single thing do they either consult, assist, or protect us. When an epidemic breaks out, locally or generally, one of the first suggestions made by sanitary authorities and local newspapers, in their panic, is to institute a house-to-house visitation; but, in fact, it is seldom attempted, and never effectually done, because it means expense, the ordinary staff being as utterly inadequate for such extraordinary efforts as it generally is unequal to ordinary requirements. But, whatever the extent of the staff, local authority has no power of inspection unless there be knowledge or reasonable suspicion of the existence of a special nuisance. In any case, the power of entry can only be enforced after compliance with certain formalities involving time and trouble; on the other hand, be the householder ever so anxious as to his safety, he cannot, of right, require an official inspection of his premises unless a nuisance is known or suspected to exist. However serious may be an epidemic, sanitary officers have no power to make house-to-house inspec tions. It does not appear to be unreasonable that local authorities should have the power, during epidemics as well as at all reasonable times, on reasonable grounds, to make house-to-house inspection, or that the ratepayers should, at all times, have the right to require such inspection. A short amending clause in the Public Health Act would readily effect all that can be reasonably expected. But to give effect to such power and satisfy the periodical demand, would impose on the local authorities the obligation of employing a sufficient staff of qualified engineering and sanitary officers. At present, at the best, sanitary inspection is not exercised in any sort of systematic manner—houses are built and drains are laid, especially, as has been said, in the suburbs of London, practically without effective supervision; and why? Not for want of power, but because of the paucity of the engineering and sanitary staff. The public are not sufficiently educated in the importance of sanitary principles to induce them to consent to the payment of the necessary staff out of the rates; but, as already shown, there is an equitable way by which ratepayers may be relieved of rates and reconciled to the existence of officials—viz., by putting the burden on the right shoulders and imposing fees upon the chief offenders against sanitary laws—those who build houses and derive profit therefrom. Such fees would, of course, go to the local authority, and not, as in London, to the district surveyor. Some years ago local by-laws required a certificate to be given before any new house was occupied, but the clause has been expunged by the Local Government as *ultra vires*. If fees are imposed by legislation, it should also be enacted that an official certificate should be granted on the satisfactory completion of a dwelling house. Such a certificate would be of real value, inasmuch as no one need then occupy a new house without its production. Sanitation would thus become a real increment of value in house property. Impressed with these views, I have, for years past, urged them, in season and out of season, long before the conception of the new limited sanitary *quasi* philanthropic companies. Some sixteen or seventeen years ago I joined in a memorial to the Home Secretary to enable local authorities to provide by fees for the proper supervision of buildings. A few years later I wrote to Mr. Gladstone on the subject, and he courteously promised to forward my letter to the proper department. For years past I have urged my own board and others to obtain Parliamentary powers to charge fees, and last year such a clause was included in a bill promoted by the West Ham local board. There was no opposition, local or otherwise; the Local Government Board not only did not object, but officially recorded its opinion that the circumstances of our case were so exceptional as to justify the application. The metropolis has long had such powers; Bristol has for forty years; even the little town of Eastbourne has such powers. With these precedents, and such exceptional reasons, a committee of the House of Commons expressed its willingness to hear our case, and waited for our evidence; but a power greater than Parliament, an *imperium in imperio*, put a veto on our clauses, and ruthlessly struck them out; this omnipotent power, Lord Redesdale, totally ignorant

of the place and the circumstances, is governed by the abstract idea that powers outside the Public Health Act should not be given to local authorities, totally disregarding the fact that every session exceptional powers are given to local authorities throughout the country in accordance with their varying necessities. No less than fourteen towns have recently obtained independent and varying local Acts for the report and registration of infectious diseases, such as smallpox, typhus, scarlet fever, &c. Why, in the name of all that is "abstract," should these fourteen towns be granted such exceptional powers not included in a general Act, applicable to all towns? Why should Eastbourne in 1879 obtain the powers which are refused to West Ham in 1881? Because, replies my Lord Redesdale, "exceptional circumstances" exist at Eastbourne. Eastbourne being a pleasant resting place from Saturday to Monday, I took the opportunity of investigating the "exceptional circumstance." A large part of the town is owned by the Duke of Devonshire, the very streets are called "Hartington," "Cavendish," and other of the family names. The duke's local agent is a leading member of the Local Board, and, whether or not he will acknowledge the soft impeachment, has the credit of obtaining the recognition of the "exceptional circumstances" applying to the pretty houses of ducal Eastbourne and those who dwell therein during "the season." That any circumstances exists, "exceptional" or otherwise, in Eastbourne which has not tenfold force in West Ham is distinctly challenged. In short, the few hundreds of the upper and middle classes who visit the toy-like town of Eastbourne are to be more exceptionally protected in their temporary dwellings than the thousands of toiling factory artisans who are compelled to live all the year round on the Essex marshes. My present object is not to discuss the wrongs of my own district, but to illustrate, by a typical case, the difficulty local authorities have to encounter in an honest and reasonable endeavor to cope with a great evil and promote sanitary well being. Here is a case in which an efficient supervision of the operations of building societies, speculating builders, and their accessory works requires an addition of some half-dozen inspectors to the local staff. "Pay them out of rates," say abstract legislators, "it is a municipal obligation;" but we municipal engineers and surveyors know too well the difficulty of obtaining decent payment for our own services to expect a sufficient assistant staff. Large towns like Liverpool, Manchester, Birmingham, or Leeds, may provide the necessary staff ungrudgingly, but it is not so everywhere. And why should such burdens be laid on the rates? Estate owners and builders are working for their own interests, many making large fortunes. Why, therefore, should they not contribute a fee, small in itself, but large in the aggregate, to provide the supervising staff, which their pursuit of fortune necessitates? Because, we are told, they already adding to the rateable value of the town; if so, they also receive, in common with others, the full value for their rates; but, as a matter of fact, such increase of buildings does not lessen the general rates, inasmuch as it involves a proportionate increase in the maintenance of roads, sewers, lighting, scavenging, police, &c., not to mention the school board and poor rates generally attending on the increase of a population. While abstract legislators, devoid of practical knowledge, are speculating, speculating builders are working; thousands of houses have been put up, and thousands more will follow before there will be any efficient control under a "general" Act. Imperial Parliament has no time for such trivial local matters. Surely there is as much necessity for "Home Rule" in England as in Ireland. Perhaps some of the members of this association will not assent to the full extent of my assertions. It is obviously derogatory alike to our pride and our efficiency as public officers to admit it; but I unhesitatingly assert, as the result of a long and varied private and official experience, that, however good our local by-laws, and however anxious and capable our local officers, as a matter of fact, there is no large town in Great Britain where, in its true meaning, sanitary supervision is efficient. Having quoted my official experience, I will crave a like indulgence in my private capacity in illustration of the defects of *old* houses. I have just entered a new residence; the

house is not new, but a good, substantial, well-built family dwelling of the last generation. In it there are as many as four cisterns; in that from which the drinking water is drawn sewer gas was "laid on" by no less than three "services" or direct connections with the house drains—viz., two flushing pipes to water closets and an untrapped overflow into the drain; each of the three pipes supplied sewer gas for absorption by the potable water; another cistern had two connections with the drain—a closet flush and an overflow pipe; a third cistern was also connected with the house drain by an untrapped overflow pipe; but, curiously enough, the fourth cistern, not intended for the supply of drinking water, was the only one unconnected with the drains. There were also two sinks in communication with the drains. In fact, within the house there were no less than nine drain connections with sinks and cisterns, exclusive of water closets. All this was altered at considerable trouble and cost, much greater than if correctly done at first. No sewer gas can now enter the house or contaminate the water. The new arrangements were regarded as "fussy," and sarcastically described as "very scientific," and as a further comment upon the sanitary theories thus practically asserted was quoted the fact, which is undoubtedly true, that in the same house the preceding family had for very many years lived very healthy lives. The obvious reply is that, according to all the laws of sanitary science, the inmates of such a house *ought* to be ill; under such conditions escape must be due either to the "survival of the fittest," that is, the inherent resistance of robust constitutions, or to the protection of a special Providence which cannot be tempted with impunity, for those who know the law and disregard it may expect and deserve "to be beaten with many stripes." Let me quote another case or two. In the civic palace of the Lord Mayor of London, ¾in. of floating fungi scrub was recently found on the surface, and ⅜in. of mud at the bottom of the cisterns, while a bottle of water on his lordship's table contained hundreds of nematoid worms. Nor is the West end of London better than the City, for in the cistern of the Athenæum Club, St. James's, was found a large quantity of offensive mud and animal organisms. The discoveries as to the insanitary condition of the Government offices are only too notorious. In poor neighborhoods and small houses, the water butts and cisterns, especially in London, are situated in close courts and contiguous to every kind of filth; generally placed over the water closet, near a sink and dust bin, untrapped pipes communicate directly from the cistern to the soil drains. They are frequently uncovered, consequently the water absorbs the impurities of the surrounding atmosphere; they are not cleaned out from one year's end to another, so that they accumulate mud and slimy vegetation. But it is unnecessary to multiply instances, or enlarge on the existence of evils so well known to us sanitary officers. To a condition of things such as above described, in houses new and old, is undoubtedly due the lassitude, the illness and the death of thousands whose inherent power of resistance is unequal to the fight. Those who are subject to such influences stand very much in the relation of the unvaccinated to smallpox; they *may* escape, but the chances are obviously against those who neglect the protection so well known and so easily attainable. I think it has been sufficiently proved that sanitary supervision is needed in our dwellings, and that it is equally obvious the work should be a public and an official one, and not undertaken by amateur or stockjobbing companies whose philanthropy is confined to shareholders. That the work has not been done before is not the fault of us officers; that it can be done, if paid for, is the very argument on which the companies are founded; but that shareholders should be protected and the poor neglected is a proposition too monstrous to be discussed. Sanitary protection is the legal right of all without subscription or "entrance fee" beyond the obligatory general charge of rates. We have seen how means can be provided without increasing the rates by charging the costs on those who can and should provide them. Surely fees are sufficiently recognized in England; from a railway station to a Government office, can any information be obtained or act done without a fee? Why a fee should be imposed on every new house in London,

Bristol, and even little Eastbourne with admitted advantage, but no other town should share in such an advantage, is inexplicable, unless it be to leave an opening for a new development of commercial enterprise in the formation of Sanitary Protective Associations (limited). It is true that an Englishman does not like officialism. We know, by experience, that it is in his nature to put himself in a fighting attitude towards officials; but if we must needs have officers, it is better to have the responsible officer of a legally constituted and recognized authority, than irresponsible employes of a limited liability company. It is a disgrace to our legislation that in England, the cradle of sanitary science, there is room for such companies. We read in the *Sanitary Engineer* of New York: "Chicago has found the results of her system of factory inspection so beneficial that she is now applying it to tenement houses. Six inspectors are now making a critical inspection of the tenements, and will continue it until the 7,000 tenements which, according to the *Chicago Times*, there are in that city, shall have been examined. The *Times* says that the work has now been reduced to a system, and complete records are kept of all work done. These records consist of date, location, ward, district, name of owner or agent, description of building, number of rooms, number of families, with the number of persons in each, sanitary condition of the building, action taken in abating nuisances found, and explanatory remarks. Each inspector is provided with blanks, which he fills out at the close of each day's work. His report describes the condition of the plumbing, drainage, the local sanitary condition, and notes any violations of the city ordinances. In case anything is found about premises which is detrimental to health, a notice is served on the owner or agent, who is required to comply with the ordinances of the city relating to the abatement of nuisances." We also read that in New York and other States household plumbing is placed under official inspection. This is the outcome of more advanced public opinion in America. I have already hinted that the British ratepayer is not yet sufficiently educated in sanitary principles; he does not yet appreciate the maxim that "Prevention is better than cure," that it is very much cheaper to employ a few inspectors than to pay the rates consequent upon preventible disease and the untimely death of the humble bread winner. I therefore submit the following propositions: That a more efficient and extended supervision of the sanitary and constructive details of all dwellings is necessary. That such supervision should be conducted by the responsible officers of the local sanitary authority. That it is just and expedient that fees be imposed on all new buildings, to provide the cost of such supervision. In conclusion, we must hope more from education that officialism. If sanitary science were studied in our schools, and our youth taught to avoid vitiated air as they would false quantities; if elementary hygiene were recognized as equal in importance with simple equations, many a good and useful life would have been saved for the commonwealth. But now, in the selection of a house, more attention is given to a "dado," a "cornice," and "æsthetic" ideas, than to the cistern, sink, or other vital conditions of health. How difficult even is it to obtain compliance with the most simple and obvious sanitary rules in one's own house! For example, whatever may be the radical defects of construction, sewer gas may at least be neutralized and kept out of the house by always keeping the closet door shut and the window open; but we almost invariably find the reverse rule to obtain, the window is *shut* and the door *open*, especially at night, when the house is almost hermetically sealed, and a current of sewer gas, induced by the warm air, enters our sleeping room at a time when our power of resistance are at their lowest. In large hotels we find at the end of a long corridor of bedrooms a battery of closets with every window shut and every door open, unless some "fussy" people, like ourselves, take the trouble to reverse the arrangement by opening the windows and closing the doors. It is unnecessary to say more. The canon laws of house sanitation are very simple and easy to observe. Builders will say that "doctors differ;" it is not so; there is no differing upon general principles; they are so well known to every member of this Association, that it is unnecessary to state them; but for the advant-

age of the general public I may be excused for repeating some of the more important of them. There should be no connection between the house and the sewers excepting for sewage; the soil pipe should not by any chance ventilate itself into the house; all other drains or pipes from cisterns, baths, lavatories, sinks, &c., should discharge into the open air; the drinking water should have no connection with the closet. These are cardinal rules, the neglect of which may be fatal; but nearly everyone can discover for himself such neglects. There are, of course, other matters more difficult to detect. We have only stated principles and facts, well known to all sanitarians, which have been repeated over and over again. But sanitarians are few, and the population is large; the population is also careless, and it is not until an unexpected, cruel and irreparable death has smitten a family with deep affliction, that conviction is forced upon the survivors, and alas! when too late, they recognize preventible causes and adopt the simple precautions and protections which, at present, are almost exclusively the privileges of the occupants of workhouses and jails.

ON METERS FOR REGISTERING SMALL FLOWS OF WATER.*

By J. J. TYLOR, of London.

From "Iron."

THE writer proposes to commence, by a short account of the chief water-meters which have been used in this country, mainly indeed for purposes of trade supply, but also occasionally for domestic supply; and also of those which are used on the Continent for domestic as well as trade supply, and which can be made available for England. In each case his special object will be to show how far the design is effective in the measurement of *small* flows.

Parkinson's Meter.—This is, in fact, an adaptation of the gas-meter, invented by Mr. Parkinson, to the measurement of water. It was described in a paper read before the Institution in 1851 (Proceedings, January, 1851, p. 19). A trough, in which the height of the water-level is maintained constant, by means of a ball-valve, passes the water entering it from the main through an overflow pipe into a rotating drum, divided into compartments. The water enters a compartment, situated on one side of the vertical axis of the drum; and thus the weight on one side being increased, the drum revolves, the full compartment sinks, and the water escapes into the case supporting the meter, and thence to the exit pipe. As the first compartment recedes another compartment takes its place, and is filled and emptied in its turn. The revolutions of the measuring drum are recorded by a train of wheels indicating on a dial; and the contents of the compartment being known, the measure is at once given. The character of this meter, which is largely in use, necessitates its being placed on the highest point of the house service. This is an objection, both on account of the exposure to frost and of the inconvenience to the consumer, in the meter inspector having to pass through the house up to the highest rooms, in order to examine the meter. The meters are, however, very reliable, and are capable of registering a very small flow of water with exactness.

Kennedy's Meter.—This meter (already described in the Proceedings, 1856, p. 156), consists of a cylinder, in which a piston, packed with a rolling ring of india rubber, works upwards and downwards. Each stroke of the piston is recorded on an index by means of a rack on the piston-rod, driving a pinion, which is fixed to a tumbler. This tumbler, by falling over its center of motion, reverses a four-way cock, serving as a supply and discharge valve. These meters are extremely reliable for any quantities passed by the meter, as long as the packing of the cylinder remains quite sound, and as

*Paper read before the Institution of Mechanical Engineers.

long as the ground-in four-way cock does not leak or jam fast. Irregularity in the section of the india rubber ring sometimes causes the piston to jam or become tilted, so that the water may pass without registration. In one of the author's experiments, a meter of this type, fresh from the maker's hands, permitted water at the rate of the full bore of a ½-inch pipe to pass without registration, owing to the fact that the piston was somehow forced by the water past the limit of its stroke, and thus got out of gear. These meters are somewhat noisy in action; and the reversal of the current at each stroke causes, at the higher pressures, considerable shocks in the mains. During the reversal of the valve, water passes without registration, though for a very short space of time; and, if the reversing balance is stiff, the meter may possibly stop at this point.

Frost's Meter.—This consists of a piston, fitted with leather buckets, working in a cylinder. The reciprocating motion of the piston is caused by a double set of valves, with ports similar to those of the steam engine. A three-port valve, worked by a cam on the piston-rod, gives motion to an auxiliary piston, set at right angles to the main cylinder, and working the main induction and exhaust valve, which is also a three-ported valve. The meter cylinder is lined with brass, and the piston has double leather buckets. Leather buckets are liable to stick and get corroded if left standing, and also wear faster than the rolling ring of the Kennedy meter. The flat three-port valves are also liable to wear round, and the mechanism is more complicated than Kennedy's. The meters, however, weigh much less and are quieter in action, registering with great accuracy at high and low velocities, as long as they are in good order. Frost is a dangerous enemy to all classes of piston meters, because, owing to their size, they cannot be cheaply protected from changes of temperature; and the expense of repair is great in such case, because the cylinder is usually the part which gives way. The water-power consumed in working these meters is considerable at quick speeds, as a heavy, tight-fitting piston has to be moved; and, in case no water passes through the meter for several weeks, the piston is apt to stick. These meters are also noisy in action, and the flow somewhat intermittent. For these reasons they are not so well adapted for small flows or for domestic purposes, as inferential meters.

Siemens' Turbine Meter.—This was brought out in two forms, one (described before the Institution, Proceedings 1853, p. 12, and 1856, p. 113), consisting of a vertical Barker's mill or reaction turbine; and the other of a turbine driven by water entering at the circumference of the wheel, and finding its way out at the center. The latter form was first tried in practice; and the writer has lately seen some of these meters, which, though useless for measuring small flows of water, seemed to be reliable for large flows. Messrs. Guest and Chrimes, the makers of these water meters, appear to have definitely adapted the Reaction Turbine; in which form this water meter has come into very extended use, both in England and abroad. The modified construction of this meter includes a reaction turbine rotating on a steel-shod pivot, provided with means of lubrication. The water enters at the upper part of the wheel or drum, which, at the point of entrance, has its neck suddenly contracted, so as to form a more or less water-tight joint, with the stationary neck conducting the water to the wheel. The water, passing downward to the larger and lower portion of this pear-shaped drum, makes its exit into the case or meter box through contracted tangential openings. The friction of the water in these openings, as well as the resistance of the more quiescent fluid in the case, causes the drum to revolve. Vanes, or drag-boards, as Dr. Siemens calls them, projecting from the moving part, prevent the increase in the velocity of the wheel being more than is proportionate to the increase in the velocity of the water; thus practically ensuring that the number of revolutions per unit of water will remain constant, at whatever speed the water may pass. It is evident that the neck forming a joint between the moving drum and the stationary case is the weak point of this meter, since any leakage at this point allows water to escape without measurement. The bearings of this neck cannot be made long or very close-fitting, as the friction of the drum is a very important element, when small flows have to be measured. Again, the neck, being

of considerable diameter, is liable to corrode and set fast, in case the meter remains long at a standstill. One great advantage of this water-meter is that the correct action of the drum does not depend on its exact fit into the outer case; so that considerable wear of the toe-piece, or vibration through the wear of the bearing, does not much affect the registration, or stop the drum by causing contact with the case.

Siemens' Fan Meter.—This differs from the former in the substitution of a wheel with blades for re-action turbine. This wheel or fan is driven by the impact of the water through oblique circular apertures in the casing, and the water, after setting the fan in motion, passes upwards towards the exit. Its velocity of rotation is checked by projecting plates, equivalent to the vanes or drag-boards of the former meter, but placed on the upper part of the case. The regulation of the meter is effected by alterations in the size of these projecting plates. This meter, which is largely used on the Continent though but little known in England, has proved successful when carefully made. The higher position of the outlet, however, diminishes the efficiency with small flows, as the water, if not projected with considerable velocity, tends to take the direct path from inlet to outlet without impinging on the blades of the fan. The wearing away of the toe-piece also causes the fan at length to come in contact with the case; and the fit of the fan in the case determines the accuracy of the registration. Further, the position of the case, below the level of the outlet, makes the meter liable to be choked by sediment; and, the case being of iron, a great quantity of rust finds its way into the moving parts, and is apt to set the fan fast in case of temporary disuse. For small flows this meter has the advantage over the other design, because in the absence of the turbine neck all water has to pass the blades of the fan, and so produces an effect on the registration as long as the quantity passing is sufficient to move the fan at all.

Tylor's Meter.—This meter, like the last, consits of a fan revolving in a case, but both fan and case differ in important points from those of Dr. Siemens. Water entering by oblique rectangular vertical openings, sets the fan in motion, and escapes at other openings on the same level, in such a way that two or more blades of the fan are always in the direct path of the water in its natural process through the meter. The fan itself consists of a solid wheel made from a preparation of india-rubber, very strong, and of almost the same specific gravity as water. It is provided with blades or teeth, which in some cases, especially for the larger sizes of meter, are made of brass. In that case the shoulder, where the blade joins the boss, is placed at an angle to the axis of the spindle, so as to tend to lift the fan at the higher velocities, and thus avoid wear of the toe-piece. The same result is obtained in the india-rubber fan by its low specific gravity. The toe-pieces for all sizes of meter are made of a special preparation of bronze, to avoid the destruction by rust to which the toe-pieces of other rotary meters, having steel points, are liable. The case is of brass, and is formed of two half ellipses, so placed together that at their junction a projection is left at each side. The fan only approaches the case at four points, namely, where the water comes in and goes out, and at the projections. The object of this peculiar form is to prevent the choking of the meter by sediment or rust, and also to prevent the current of water from continuing to turn the fan after the source of supply is shut off. This obviates the common difficulty in rotary meters, namely, that the moving part of the meter continues to rotate for some revolutions after the water has ceased to pass. This motion is partly caused by the *vis viva* of the fan, and partly by a current of water continuing to revolve in the lower part of the meter case, and carrying the fan round with it, after flow through the meter has ceased. In the present meter the projections in the case regulate the movement of the fan at the greater velocities, so that a unit of water moving at a high velocity is prevented from causing more revolutions of the fan than a unit of water at lower velocity; while the centrifugal force of the water produces a back current from the projections, and breaks up any tendency the water may have to continue rotating after the flow through the water ceases. Another improvement in this meter is an application

for regulating the speed of the fan by a counter current of water, so arranged that it is adjustable from the outside of the case. This is of great convenience in testing, and also for persons making use of these meters, since any error in registration, springing from long use or accident, can be remedied without taking the meter to pieces or sending it back to the manufacturer. The defect of this meter is that, like all rotary meters, it is liable to pass a certain quantity of water without registration. This quantity can be limited to an amount comparable with the minimum registration of piston meters; but at the expense of rendering the meter too delicate for use in corrosive water. In concluding this part of the paper, the author wishes to draw attention to the great influence of Dr. Siemens' invention on the introduction of rotary meters, and to the fact that to his original designs all the rotary meters which have come into use owe their principles of construction.

Measurement of Small Flows.—In practice abroad, where rotary meters are mostly employed for domestic supply, a meter having moderate accuracy with very small flows is found the most advantageous. Cisterns are not in use, and the consumer cannot therefore conveniently defraud the company by allowing the water to trickle slowly. As a matter of fact, it is certain that in ordinary use but a small quantity of water is drawn at very slow speeds in domestic supplies. Accordingly in Russia, Germany Austria, Italy, and France, the rotary meters described in this paper are used almost exclusively for domestic supply, and the payments for water are collected according to the registration of the meters. In England detailed experiments have always been made in practice, as far as the author is aware, with quantities sufficient for trade supplies, and therefore run at considerable speeds. If, however, meters are to be employed for domestic service, it will be necessary to register small quantities, at least in cases where cisterns are used, and the question arises how far the existing meters are capable of performing this function. Now the experience of the Continent proves that there is no difficulty in registering small quantities, whether with a rotary or piston meter, provided they are not drawn at a very low speed. If the speed be very slow, then a rotary meter, at any rate, becomes less reliable. Assuming that this is not the case with the piston meter, we may fix a rotary and piston meter together on the main of the dwelling house, and then see whether there is any marked difference between the registration of the two, indicating that a portion of the water has been drawn very slowly. Three experiments of the kind are given in Tables I.-III. annexed, for houses of different classes; and it will be seen that while the difference is usually small, the rotary meter shows the greater flow, proving that in practice no error arises from this cause. In these cases both meters were tested with measured quantities, both before and after the experiments, in order to make sure that they were in good order. Table IV. gives a similar trial carried out in Edinburgh, and here the rotary meter shows a distinct deficiency; but the variations between the two piston meters are also noticeable.

House Meters.—The general question of the introduction of meters for domestic supply in England is a very large one. Into its financial and economical aspects the writer does not propose to enter; but only to point out the great advantage of meters as a means of preventing waste, and thereby of increasing the efficiency, and diminishing the cost of the service, under whatever system that service may be administered. If the water companies were willing to grant supply by meter instead of by rate, there would be no difficulty in arranging existing meters to fulfil any conditions necessary. To provide against loss of water by waste from the main, or in supplies not controlled by a water meter, some account of the system introduced by Mr. Deacon at Liverpool, with his waste-water meter, and carried out by Mr. Muir of the New River Water Company, and other engineers, will prove of service. The following is a description of an apparatus for the same purpose, which has been applied by the author to the existing Taylor meter. Above the meter, the movements of which are to be recorded, and fixed to the upper flange, is placed clockwork, so constructed as to move a strip of paper, about 1 inch broad, horizontally, and with an intermittent move-

ment, under a pencil or pen free to move transversely. This pencil or pen is connected by a cam and train of wheels with the registering pinion of the water meter, in such a way that the movement of the pencil across the strip of paper corresponds to 500 or 1000 gallons registered by the water meter. The completion of the movement of the pencil across the paper is marked by its sudden return to the side of the strip of paper whence it started, and the interval between the ascending serrated mark and the return vertical mark corresponds to the time occupied in the passage of the above quantity of water. The time is also marked every hour independently by a pricker connected with the clock, as a check.

In some of the recently erected workmen's dwellings it has been ascertained that the total consumption of water, including washing of clothes, does not exceed six gallons per head, and this is for the better class of artisans. The author has made many experiments on this point, and whilst the differences in consumption, in houses of the same class, are found to be very large. it is clear that six gallons per head is really sufficient. Tables V. and VI. give two cases of this kind, in houses of very similar character. The large fluctuations from day to day will be remarked, and also the fact that in one case the consumption per head per diem was $14\frac{1}{3}$ gallons, and in the other $4\frac{3}{4}$ gallons only. In the latter case, however there was also a small rain-water cistern in use. Again, in houses of the middle classes, it is known that the quantity of water actually used for cooking, washing, and all other purposes except baths, is not more than ten gallons per head, and for baths five gallons per head will be a very ample allowance. It will therefore be on the safe side to assume that the actual consumption per head for all purposes should not exceed fifteen gallons for medium-sized houses, and ten gallons for small; making in the latter case a large allowance for the increased consumption in single tenements, as compared with dwellings in flats. But it is known that the London waterworks supply on an average upwards of 27 gallons per head of the population; so that it appears that nearly half the total supply is absolutely wasted.

If by a proper system of domestic meters this enormous waste could be checked and brought within proper limits, the advantages, both to the water companies and to the consumer, must obviously be great. The increased pressure and service, resulting from the diminished drain on the mains, would enable a constant supply to be maintained at the top of every house during the day; and would thus do away with the need of cisterns for storage, which are always stagnant and often polluted. To the companies the reduction in the cost of pumping and other expenses would pay for the whole expenses of supplying and maintaining the meters, and leave a very large surplus. For instance, the report of the Committee in 1880 shows that the average gross income of all the London Waterworks is at the rate of less than 7d. per thousand gallons, and that the trade supply is about one fifth of the whole. Now if the water rates were raised by a charge of 1s. per thousand gallons of measured water, divided into average charges of 6d. for trade and 1s 2d. for domestic purposes, it will be seen that the water companies of London would (if waste in the mains be limited to 8 per cent.) profit to the extent of 4d per thousand gallons on the present supply. On the other hand (as shown by Table V.) even the most extravagant consumer would for an efficient supply pay less than he now does; but as long as his fittings were out of order he, and not the water company, would pay for the wasted water.

TABLE. I.

Experiments carried out at the Lincoln Waterworks, with Constant Service, showing the Relative Monthly Registration of a Rotary and Piston Water Meter.

Month.	Rotary Meter, gallons per diem.	Piston Meter, gallons per diem.
March	97	96
April	102	101
May	199	177
August.....	83	77
October.....	90	86
Total for 5 months....	19,575 Gallon.	18,188 Gallon. (7 per cent. less).

The consumption in this experiment corresponds with that of an ordinary workman's house in London, with con-

stant supply, containing 8 persons, and using on an average 13.07 gallons per head per diem.

TABLE II.

Experiments with Piston and Rotary Meter, both ½ inch, on a house and tobacco shop, containing 8 persons of whom 3 were away from 6 A. M. to 6 P. M.: 1 bath ; 2 w. c.'s.

Date.	Rotary Meter. Average gallons per diem.	Piston Meter. Average gallons per diem.
1880.		
Dec. 23-26....	117	115
Dec. 27-30....	182	195
1881.		
Dec. 31.-Jan 3	152	138
Jan. 4-Jan. 7.	122	118
Jan. 8-Jan. 11 (Frost).	145	122
Jan. 12-Jan.14 (Severe frost).	166	150
Average....	147	140 (4.75 per ct. less)

N. B.—On January 14th, the pipes were frozen till Feb. 8th, when the piston meter burst. The rotary meter recorded 240 gallons on Feb. 9th, and 100 on Feb. 10th.

This case represents a large class of houses used as small shops, with two or three lodgers besides the family. The average consumption is 17.75 gallons per head per diem.

TABLE III.

Experiments with Rotary and Piston Meters on main of a house in the Chelsea District. Number of family 12 to 14 persons; 2 baths; 4 w. c.'s. Supply constant during daytime.

Date.	Rotary Meter. Gallons per diem.	Piston Meter. Gallons per diem.	Remarks.
Feb. 17	150	Out of order	14 persons in a house.
" 18	915	"	" "
" 19	945	"	" "
" 21	940	"	Family left.
" 23	300	290	Cleaning.
" 24	515	550	Cleaning, family returned
" 25	535	500	Family left.
" 26	450	410	Leaky ball valve rep'rd.
" 27	423	405	
" 28	423	405	Family returned.
Mar. 1	474	470	12 persons in house.
" 2	530	490	" "
" 3	415	400	" "
" 4	513	490	" "

This was a house occupied by a member of Parliament, at a rent of £350 per annum. The average consumption, from Feb. 23d to April 11th, had been at the rate of 22.5 gallons per head per diem. But previous to repair of fittings on Feb. 26th, the average consumption was at the rate of 31.3 gallons per head.

TABLE IV.

Experiments with Piston and Rotary Meters carried out by Mr. Coyne, Engineer of the Edinburgh Waterworks, for his own information. Meters were placed on a public service and close together; constant service.

No. of Experiment.	Duration of trial	No. of Days.	Rotary Meter.	Piston Meters.	
			Gallons registered.	No. 1 Gallons regis'ed	No. 2 Gallons regis'ed
1	April 21, 1879 to Feb. 14, '80	267	150,050	not fix'd	161,600
2	Feb. 15, 1880 to June 3, '80	109	46,200	not fix'd	54,000
3	June 3, 1880 to Aug. 16, '80	74	47,700	54,000	52,650
4	Oct. 27, 1880 to Feb. 10, '80	116	34,160	36,100	38,700
Tot.	April 23, 1879 to Feb. 19, '81	596	278,110	—	306,950

TABLE V.

Quantity of Water registered by ½-in. Rotary Meter in a House containing 5 people, all washing done at home ; 1 bath, 1 w.c. Intermittent supply.

Date.	Per Meter, Gallons consumed.	Gallons per Head daily.
Sat. Nov. 20...	210	42
Sun. " 21...	60	12
Mon. " 22...	90	18
Tues. " 23...	50	10
Wed. " 24...	40	8
Thur. " 25...	50	10
Fri. " 26...	60	12
Sat. " 27...	80	16
Sun. " 28...	60	12
Mon. " 29...	50	10
Tues. " 30...	60	12
Wed. Dec. 1...	50	10
Thur. " 2...	40	8
Fri. " 3...	310	62
Sat. " 4...	90	18
Sun. " 5...	50	10
Mon. " 6...	90	18
Tues. " 7...	60	12
Wed. " 8....	250	50
Thur. " 9..	30	6
Fri. " 10...	60	12

N.B.—3010 gallons consumed in six weeks, ending Dec. 10. Daily average 70⅓ gallons, or 14⅓ gallons per head. Rent of house £40 per annum; water rate, 41s. Water used by meter in six months was 13,080 gallons, which at 1s. 2d. per thousand is equal to 30s. per annum.

TABLE VI.

Quantity of Water registered by a ¾-in. Rotary meter, fixed on a House in the Lambeth District, containing 7 rooms: 1 w.c., garden 120 by 16. All washing done at home. Number of family, 6.

Contents of Cistern 7.7 cubic feet, or about 50 gallons. Meter gave 50 gallons when tested at commencement of trial.

Date.	Gallons per Day.	Gallons per Head per Day.
Nov. 20.....	30	5.0
,, 21.....	30	5.0
,, 22.....	20	3.3
,, 23.....	30	5.0
,, 24.....	20	3.3
,, 25.....	30	5.0
,, 26.....	55	9.1
,, 27.....	5	0.8
,, 28.....	40	6 6
,, 29.....	10	1.66
,, 30.....	20	3.3
Dec. 1.....	20	3.3
2.....	25	4.1
3.....	30	4.1
,, 4.....	5	0.8
,, 5.....	20	3.3
,, 6.....	50	8.3
,, 7.....	45	7.5
,, 8.....	45	7.5
,, 9.....	50	8,3
,, 10.....	40	6.6

Total water in 124 days, 3180 gallons; average per diem, 25.56 gallons; average per head per diem, 4.75 gallons. Meter, when tested at different intervals during trial, showed 48 gallons for contents of cistern. The supply being intermittent and the meter placed near the cistern, this error is probably due to air in the pipes, as the meter was exactly correct when tested at the manufacturers. The cistern was allowed to fill with the ball valve closing gradually, in the usual way, in these intermediate tests. In reference to the small consumption in the house, it appears that a rain-water cistern containing 50 gallons is in use, the water from which is used, when obtainable, for any purposes except for drinking and for cooking.

A NEW invention for coating iron and steel with iridescent copper, says the *Revue Polytech*, is the work of Dr. Weil, of Paris. First, thirty-five parts of crystalized sulphate, or an equivalent amount of any other salt of copper, are precipitated as hydrated oxide by means of caustic soda or some other suitable alkaline base; this oxide of copper is to be added to a solution of 150 parts of Rochelle salts, and dissolved in 1000 parts of water; to this 60 parts of best caustic soda, containing about 70 per cent. NaO, is to be added, when a clear solution of copper will be formed. The object to be coppered is to be cleaned with a scratch brush in an alkalino-organic bath, attached as a cathode, immersed in the coppering bath, and treated with the usual precautions, when it will become rapidly coated with an adherent film of metallic copper. As the bath gradually loses its copper, oxide of copper, as above prepared, should be added, to maintain it in a condition of activity, but the quantity of copper introduced should not ordinarily exceed that above prescribed, as compared with the quantity of tartaric acid the bath may contain. If the quantity of copper notably exceeds this proportion, certain metallic iridations are produced on the surface of the object. These effects may be employed for ornamental and artistic purposes. According to the time of the immersion, the strength of the current, and the proportion of the copper to tartaric acid, the iridescences may be produced of different shades and tints, which may be varied or intermingled by shielding certain parts of the object by an impermeable coating of paraffine or varnish, while the iridescent effect is being produced on the parts left exposed. All colors, from that of brass to bronze, scarlet, blue and green may thus be produced at will.

THE Italian Minister of Public Works has given orders for surveying a direct railway line from Naples to Rome, *via* Gaeta and Terracina, which was proposed in 1871 by the engineer Danise. Rome could be reached by that route in three and a-half hours, while now double this time is employed. Strategical considerations will have some weight, as the new line would give mutual support to the fortress of Gaeta and Capau.

SUSPENSION BRIDGES OF ANY DESIRED DEGREE OF STIFFNESS;

OR, THEORY OF EQUILIBRIUM OF A LOADED ELASTIC BEAM SUSPENDED FROM AN ELASTIC PARABOLIC CATENARY.

By C. B. BENDER, C.E.

Only few combinations of two elastic systems admit of a strict analytical treatment, and many combinations are only the result of arbitrary guessing without a sufficiently clear understanding of the acting forces.

Such designs, when executed, represent only so many unscientific experiments on a large scale.

The combination, however, of a homogeneous elastic beam suspended from a flexible catenary, is one of the few which are capable of a tolerably rigid analytical treatment.

It is a very useful combination.

Though frequently examined—so far as known to the writer—it was always supposed to be made with a beam so stiff that the assisting influence of the *distortion* of the parabolic catenary could be neglected.

That this supposition may lead to considerable errors, will result from the solution of the problem now presented, and worked out by the writer at the commencement of the year.

The combination of catenary and suspended beam is especally useful for very great spans, and has become more so since, thanks to the inventions of Messrs. Siemens and of Sir H. Bessemer, steel wire of great strength and uniformity can be produced in great masses at a reasonable cost.

It is now possible to construct galvanized steel wire cables of 70 and more tons of ultimate strength per square inch of metal of the finished cables. Moreover, wire is furnished (first in Germany, where the wire industry occupies many works, and not only supplies nearly exclusively the home market, but also brings 70,000 and more tons of this article yearly to export) in coils of about a hundred weight each, so that the joints of cable wires are more than 1500 feet apart.

Since the capacity of elastic material for absorbing tensional impacts within the elastic limit, increases in direct ratio of the lengths, long wires are capable of withstanding the influence of movable loads better than riveted structures, or even of ordinary bridge links, which were never made in lengths greater than a little over 50 feet.

By good connections, about 5 to 10 per cent. of the original strength of the wire is lost. Eye bars of 25 feet length, if made 6″ wide, require 16 per cent. additional material for eyes and pins. If made 3″ wide only 8 per cent. would be needed. Galvanized steel wire of No. 8 gauge can be furnished in great masses with an ultimate strength of about 160,000 pounds per square inch area. For steel eye-bars not more than 70,000 pounds must be counted on, and for good ductile iron eye-bars 50,000 pounds. Wire is considerably dearer per ton than bars, but requires only machine labor to make the connections. It is easily put in place, but requires much time for its manufacture into cables.

For very great spans cables seem to have the preference, not only on account of their durability, due to galvanizing and wrapping, but, also, because their strains are known with great certainty, and because of the great distance of wire joints which permit the adoption of a lower factor of safety. (Compare "Cable Making for Suspension Bridges," by Wilhelm Hildenbrand, the scientific and conscientious assistant, since the commencement of the East River Suspension Bridge, of the late John A. Roebling and his son, W. Roebling, the engineers of that structure). The suspended beam not only has the office of distributing the concentrated loads, and of neutralizing the greater part of the momenta caused by one-sided loads, but also furnishes a sufficient quantity on both sides of the bridge floor, which serves to form chords for the horizontal wind bracing.

Additional arrangements, as inclined stays, are not only not needed, but lead

to waste of material and labor, because the point of attachment of each stay, under certain positions of the movable load, is taxed with a high moment of flexure. These stays, and similar additional appliances, lead to uncertainty of all strains, and hence to unscientific rule-of-thumb design and to disturbance, under the influence of changing temperatures of the conditions of equilibrium.

The *beam, if properly designed*, is all what is wanted; it is *necessary and is sufficient!* It does away with those uncertainties, and gives the greatest simplicity and economy for the greatest possible spans.

In order to examine the conditions of equilibrium of this useful combination reference is had to the following diagram and notations.

Let these represent:

ACB, the original parabolic catenary.

A′C′B′, its position in equilibrium under the loads supposed.

$2b$, the distance AB=A′B′, its span.

H, its original depth.

$y=\varphi(x)=h-\frac{2\mathrm{H}.x}{b}+\frac{\mathrm{H}.x^2}{b^2}$ its original equation.

O′, the origin of co-ordinates.

O′O″, the positive side of the abscissæ x.

O′A, the positive side of the ordinates y.

πx, the intensity for the abscissæ x of forces acting in suspenders, supposed to be infinitely close together, and representing a load per unit of length of x.

Q, the constant horizontal component of the tension of the cable A′C″B′ for any abscissæ x, it being the result of all weights acting upon the system. A flexible cable is supposed.

E, the modulus of elasticity of material, it being supposed to be constant throughout.

h, the original length of the longest suspender.

$h-\mathrm{H}$, the original length of the shortest suspender.

O′O″=$2b$, the length of the suspended beam.

R_1 a possible *positive* reaction, the positive sign being used for supporting forces acting upwards towards the positive y.

W_1 W_{11} W_{111}, negative concentrated forces: weights.

$2\,b$. K, an uniform permanent weight, K being its intensity″ per unit of length of beam.

$z\,p$, another uniform and movable weight, z=O′z being variable.

l_1 l_{11} l_{111}, the levers taken for O′ of the weights W_1 W_{11} W_{111} in their position on the system in equilibrium.

M′o, the moment of all weights W, p and K for O′.

M″o, the moment of all weights W, p and K for O″.

These moments are connected by the equation $\mathrm{M}'o+\mathrm{M}o''=2b\,(\mathrm{W}_1+\mathrm{W}_{11}+\mathrm{W}_{111}+\ldots+2\,b\,\mathrm{K}+z.p)$=span×sum of all weights.

I, the constant moment of inertia of the suspended beam. This is supposed to be homogeneous, and of such nature that its deflections are not influenced by the shearing forces (web members), but only by the moments of flexure (chords or flanges). A moment of flexure for a certain abscissa is positive, if the radius of curvature at the point contemplated is directed towards the positive side of the y, or if the center of curvature is above O′O″. The second differential quotient, therefore, of the equation of the curve of flexure for that point is positive, and the positive moment means a curve concave towards the side of the positive y, with pressure in top fibers and tension in the bottom fibers of the beam. A negative moment arises from a negative second differential quotient, causes a curve of flexure, which is concave towards the negative y, and causes tension in the top and pressure in the bottom fibers of the beam.

A shearing force is considered positive if acting in a sense opposite to that of the weights imposed upon the bridge. For a certain abscissa x, it is equal to : R_1 plus all forces $\pi x.dx$ less the weights between the point O′ and the point contemplated.

In accordance with these notations, suppositions and explanations, the problem consists of finding the equation of the elastic curve of the beam. Its unknown equation $y=f'(x)$ is to be found where y are ordinates, as distinguished from those of the cable, which are denoted with y. If, for instance, the beam deflects, which here means that y is negative, and if the suspender, for a certain $x=x_1$, originally had the length y and

now becomes $y(1+\varepsilon)-\varepsilon$ being the specific extension of the suspender due to the value πx_1 : the new ordinate y' of the catenary A′C′B′ will be equal to $y(1+\varepsilon)$ *less* the *absolute* value of y or it will be $y(1+\varepsilon)+f'(x)$ and $y'=\psi(x)=\varphi(x)+f'(x)$ . . . . (1).

This simple equation characterizes the connection between the two elements of the combination to be examined. The small and variable fraction ε need only be considered in a calculation of correction. The moment of flexure Mx_1 for $x=x_1$ can be expressed in two ways.

a.) It is equal to

$$E.I.\frac{d^2y}{dx^2}=E.I.f''(x)$$

in accordance with Euler's fundamental equation.

b.) Taking the point for which $x=x_1$ as fulcrum, it is equal to the moment of all exterior forces acting on $O'x_1$, care being taken that in agreement with the form of the curve, the moment so found has the same sign as $\frac{d^2y}{dx^2}$. Consequently the moment is

$$Mx_1=R_1.x_1-W_1(x_1-l_1)-W_{11}(x_1-l_{11})-\ldots-(p+k).\frac{x_1^2}{2}+\int_o^{x_1}[\pi_x(x_1-x).dx]$$

a.) and *b.*) are equal, hence there is already found the relation looked for, which only needs simplification. As regards the integration *b.*), the differential quotient of $\psi(x)\times Q$ represents the load carried by the cable. The differential quotient of the product or $Q.\frac{d^2\psi(x)}{dx^2}$ is the intensity π_x by which the shearing force changes at x. Hence:

$$\pi_x=Q\frac{d^2\psi(x)}{dx^2}=Q.\left\{\frac{2.H}{b^2}\frac{(1+\varepsilon)}{}+f''(x)\right\}$$

which is an absolute value. The integral in *b.*)

$$\int_o^{x_1}[\pi_x(x_1-x).dx]=x_1\int_o^{x_1}\pi_x dx-\int_o^{x_1}[x.\pi_x.dx]$$ becomes $=Q.x_1.$

$$\int_o^{x_1}\left\{\frac{2.H.(1+\varepsilon)}{b^2}+f''(x)\right\}dx-Q.\int_o^{x_1}x\left\{\frac{2.H.(1+\varepsilon)}{b^2}+f''(x)\right\}dx$$

and omitting $(1+\varepsilon)$ which is tied to H and simplifying

$$=Q.\frac{x_1^2.H}{b^2}+Q.x_1.\int_o^{x_1}f''(x)dx-Q\left\{f'(x).x\right\}_o^{x_1}+Q.\int_o^{x_1}f'(x).dx.$$

$$=Q.\frac{x_1^2.H}{b^2}+Q.x_1.f'(x_1)-Q.x_1.f'(x_1)+Q.f(x_1)-Q.f(x_o)$$

where $f(x_o)$ is a constant value and two other constants have disappeared. Finally the integral is obtained

$$=Q.x_1^2.\frac{H}{b^2}+Q.f(x_1)+\text{constant}.$$

This value introduced into eq. *b.*) the values *a.*) and *b.*) furnish for M_{x_1}, at the point where the abscissa is x_1, the value

$$E.I.\frac{d^2y}{dx^2}=R_1.x_1-W_1(x_1-l_1)-W_{11}(x_1-l_{11})-W_{111}(x_1-l_{111})-\ldots-(p+k)\frac{x^2}{2}+Q.x_1^2.\frac{H}{b^2}+Q.f(x_1)-Q.f(x_o)$$

Now all x have disappeared and M_{x_1} is only expressed by x_1, so that simply returning to x and after two differentiations the fundamental equation

$$E.I.\frac{d^2y}{dx^2}=-(p+k)+\frac{2.Q.H}{b^2}+Q.\frac{d^2y}{dx^2}. \quad (2.)$$

is obtained.

This equation can be simplified in appearance by putting

$$\left.\begin{aligned}&E.I=Q.t^2 \text{ and}\\ &z=\left(\frac{d^2y}{dx^2}+\frac{2.H}{b^2}+\frac{p+k}{Q}\right)\end{aligned}\right\} \ldots (3.)$$

whereupon the equation follows

$$\frac{d^2z}{dx^2}-\frac{z}{t^2}=o$$

which integrated leads to the expression

$$z=A.e^{\frac{x}{t}}+B.e^{-\frac{x}{t}}$$

where $e=2.7182818$, or

$$\frac{d^2y}{dx^2}=A.e^{\frac{x}{t}}+B.e^{-\frac{x}{t}}+\left(\frac{p+k}{Q}-\frac{2.H}{b^2}\right)$$

$$\frac{dy}{dx}=t.\mathrm{A}.e^{\frac{x}{t}}-t.\mathrm{B}.e^{-\frac{x}{t}}+\left(\frac{p+k}{\mathrm{Q}}-\frac{2\mathrm{H}}{b^2}\right).x+\mathrm{C}$$

$$y=t.^2\mathrm{A}.e^{\frac{x}{t}}+t.^2\mathrm{B}.e^{-\frac{x}{t}}+\left(\frac{p+k}{\mathrm{Q}}-\frac{2.\mathrm{H}}{b^2}\right).\frac{x^2}{2}+\mathrm{C}.x+\mathrm{D} \quad . \quad . \quad . \quad (4.)$$

which is the equation $f_1(x)$ for the branch from $x=o$ to $x=z$; A, B, C, D and t are unknown constants which must suit, firstly the general conditions of rigid bodies in equilibrium, and secondly the end conditions of the system. In the following pages the loads W are left off and only p and k are retained.

For the part of the curve from $x=z$ to $x=2b$ a similar equation is obtained, O′ being kept as origin

$$f_{11}(x)=y_{11}=t.^2a.e^{\frac{2b-x}{t}}+t.^2\beta.e^{-\frac{2b-x}{t}}+\left(\frac{k}{\mathrm{Q}}-\frac{2\mathrm{H}}{b^2}\right)\frac{(2b-x^2)}{2}+px+\delta \quad . \quad . \quad (4a)$$

where a, β, γ and δ are new constant values.

The general conditions of equilibrium of rigid bodies, here applied, require that the algebraic sum of the moments of all the forces acting thereon, including reactions, for any point must be equal to zero, and that also the algebraic sum of the parallel weights and reactions be equal to zero. The moments taken for O′ and O″ include the second condition.

Taking the fulcrum O″ the moment of the weights is M_o''. At A′ the reaction of the cable is $-\mathrm{Q}.\psi'(o)$ [negative sign because $\psi'(o)$ is negative, and reaction positive]. The reaction of the beam at O′ is R_1, and the moments $\pm\mathrm{Q}.h$ disappearing, $\mathrm{M}_o''=2b[\mathrm{R}_1-\mathrm{Q}.\psi'(o)]$. For the value $\mathrm{R}_1=\mathrm{E.I.}\frac{d^3y}{dx^3}$, x at O′ being O, the value $\mathrm{E.I.}\left(\frac{\mathrm{A}}{t}-\frac{\mathrm{B}}{t}\right)$ is obtained from eq. (4.).

For $\psi(o)$ is got $\varphi'(o)+f''(o)$, or consequently

$$\frac{\mathrm{M}_o'''}{2b}=\frac{\mathrm{E.I}}{t}(\mathrm{A}-\mathrm{B})-\mathrm{Q}.\mathrm{C}-\mathrm{Q}.t(\mathrm{A}-\mathrm{B})+\frac{2.\mathrm{H}.\mathrm{Q}}{b}$$

and since $\mathrm{E.I}=t.^3\mathrm{Q}$,

$$\frac{\mathrm{M}_o''}{2b}=-\mathrm{Q}.\mathrm{C}+\frac{2.\mathrm{H}.\mathrm{Q}}{b_1}$$

hence

$$\mathrm{C}=\frac{2\mathrm{H}}{b}-\frac{\mathrm{M}_o''}{2b.\mathrm{Q}} \text{ and } p=\frac{2.\mathrm{H}}{b}-\frac{\mathrm{M}_o}{2b.\mathrm{Q}} \quad . \quad (5.)$$

The assumption of certain end conditions of the system may now be proceeded with:

The beam O′O″ is supposed to be without end moments and to be provided for ± end reactions R. Hence for

$$\left.\begin{aligned} x=o, \mathrm{M}_x=o, \mathrm{A}+\mathrm{B}=-\left\{\frac{p+k}{\mathrm{Q}}-\frac{2.\mathrm{H}}{b^2}\right\}=\mathrm{C}_1 \\ x=2b, \mathrm{M}_{2b}=o, a+\beta=-\left\{\frac{k}{\mathrm{Q}}-\frac{2.\mathrm{H}}{b^2}\right\}=\mathrm{C}_{11} \end{aligned}\right\} \quad . \quad (6.)$$

where C_1 and C_{11} are introduced for the sake of brevity.

To obtain further conditions for the determination of constants it is now desirable to consider that the two branches of the elastic curve must be identical for $x=z$. This condition requires that:

$$y_1=y_{11};\ f_1'(z)=f_{11}'(z);\ f_1''(z)=f_{11}''(z);\ f_1'''(z)=f_{11}'''(z)$$

or that the ordinates, the tangents, the moments and the shearing forces must be equal for $x=z$. (7.)

Hence

$$(a.)\ t.^3\mathrm{A}.e^{\frac{z}{t}}+t.^3\mathrm{B}.e^{-\frac{z}{t}}-\mathrm{C}_1.\frac{z^2}{2}+\mathrm{C}.z+\mathrm{D}=t.^3a.e^{\frac{2b-z}{t}}+t.^3\beta.e^{-\frac{2b-z}{t}}-\mathrm{C}_{11}\frac{(2b-z)^2}{2}+\gamma(2b-z)+\delta.$$

$$(b.)\ t.\mathrm{A}.e^{\frac{z}{t}}-t.\mathrm{B}.e^{-\frac{z}{t}}-\mathrm{C}_1.z+\mathrm{C}=-t.a.e^{\frac{2b-z}{t}}+t.\beta.e^{-\frac{2b-z}{t}}+\mathrm{C}_{11}.(2b-z)-\gamma$$

$$(c.)\ \mathrm{A}.e^{\frac{z}{t}}+\mathrm{B}.e^{-\frac{z}{t}}-\mathrm{C}_1=a.e^{\frac{2b-z}{t}}+\beta.e^{-\frac{2b-z}{t}}-\mathrm{C}_{11}$$

$$(d.)\ \frac{\mathrm{A}}{t}e^{\frac{z}{t}}-\frac{\mathrm{B}}{t}e^{-\frac{z}{t}}=-a.e^{\frac{2b-z}{t}}+\beta.e^{-\frac{2b-z}{t}}$$

From (*a.*) and (*c.*) results

$$D-\delta=\frac{p.t^2}{Q} \quad . \quad . \quad . \quad . \quad (8)$$

Since D and δ only appear in (*a.*) nothing further about them is known for the present. But the values y for O′ and O″ are found $=t^2(A+B)+D$ and $t^2(\alpha+\beta)+\delta$ and their difference $y_a-y_{2b}=t^2(C_1-C_{11})+p.\frac{t^2}{Q}=$ nothing, or the end deflections must be equally great. Also A′ and B′ must be on a level. On account, therefore, of the extended suspenders and compressed towers, a little freedom must be given at O′ and O″ so that under one-sided loads a small distortion will precede the regular action of the forces, one of the points O′ and O″ being a little higher than the other. The towers need not support exactly at A and B, they can stand a little behind, and the end pieces of the cables can be arranged to accommodate the distortion mentioned.

From (*b.*) and (*d.*) follows $-z.C_1+C=C_{11}(2b-z)-\gamma$ which does not give any new information, so that really there are only three equations instead of four. From (*c.*) and (*d.*) can be obtained:

$$\alpha.\left(e^{\frac{2b}{t}}-e^{-\frac{2b}{t}}\right)=C_1-C_{11}.e^{-\frac{2b}{t}}+\frac{p}{2Q}\left(e^{\frac{z}{t}}+e^{-\frac{z}{t}}\right)$$

$$\beta.\left(e^{\frac{2b}{t}}-e^{-\frac{2b}{t}}\right)=-C_1+C_{11}.e^{\frac{2b}{t}}-\frac{p}{2Q}\left(e^{\frac{z}{t}}+e^{-\frac{z}{t}}\right)$$

$$A.\left(e^{\frac{2b}{t}}-e^{-\frac{2b}{t}}\right)=C_{11}-C_1.e^{-\frac{2b}{t}}-\frac{p}{2Q}\left(e^{\frac{2b-z}{t}}+e^{-\frac{2b-z}{t}}\right) \quad (10.)$$

$$B.\left(e^{\frac{2b}{t}}-e^{-\frac{2b}{t}}\right)=-C_{11}+C_1.e^{\frac{2b}{t}}+\frac{p}{2Q}\left(e^{\frac{2b-z}{t}}+e^{-\frac{2b-z}{t}}\right)$$

and also

$$A.e^{\frac{z}{t}}=\beta.e^{-\frac{2b-z}{t}}-\frac{p}{2Q} \text{ and}$$

$$B.e^{-\frac{z}{t}}=\alpha.e^{\frac{2b-z}{t}}\frac{p}{2Q} \quad . \quad . \quad (9.)$$

from which (10.) were derived with utilization of (6.)

In order to determine Q and t another condition is needed. This condition consists of the known length of the cable which, under the strains containing analytically only the unknown quantity ″Q, would stretch in a degree which can be expressed by an equation.

The new length, also expressed by an integral, would have to be equal to the original length plus the extension, the analytical expression of the whole condition is very complex. But by making a hinge in the center of the beam, and thus also avoiding strains and intricate calculations due to changes of temperature all complication is avoided.

Already before Koepke, in 1860, made this observation, a Prussian Government Commission reported that the trusses of the Niagara Railroad Suspension bridge, to avoid considerable additions to the strains, should be interrupted in the center. (*See* Erbkam's Zeitschrift für Bauwesen, Berlin).

Supposing now that $z \gtreqless b$ and that there is a hinge in the middle, there must become $M_{x=b}=0$ or $\alpha.e^{\frac{b}{t}}+\beta.e^{-\frac{b}{t}}-C_{11}=0$, which with (10.) gives the equation (11.)

$$(1-e^{\frac{b}{t}})(1-e^{-\frac{b}{t}}).2.C_{11}.Q=p.(1-e^{\frac{z}{t}})(1-e^{-\frac{z}{t}}) \quad . \quad . \quad . \quad (12.)$$

so that for $z=b$, or in case that the bridge is half loaded $2.Q.C_{11}=p$, $Q=\left(k+\frac{p}{2}\right)\frac{b^3}{2H}$,

$$C_{11}=-C_1=\frac{p.H.}{b^3.(k+p_2)}-\alpha=-A;\ \beta=-B. \quad . \quad . \quad . \quad . \quad . \quad (13.)$$

Hence, if the bridge is half filled with uniform load p, the cables—as far as Q is concerned—are strained as if the moving load p b were spread over the whole

span with the intensity p_2 *and* as if the cables were still hanging in parabolic curves.

But it does not follow that their form is parabolic. It results from (13.) that the equations for the moments of both halves of the beam are identical, but of opposite signs.

An interesting quality of the hinged beam, when half loaded, is this. According to (13.) y_1 and y_{11} for symmetrical points x_1 and $2b-x_1$ by adding give

$$y_1+y_{11}=D+\delta=\text{a constant value.}$$

It also follows from (6), (10) and (13) that under full load K, or full load $(p+k)$, C_1 is equal to C_{11} and that $\alpha=\beta=A=B=$zero, and that all moments become zero. There is also $M_o''=M_o'$ or $C=\gamma=o$ and only D remains$=\delta$.

Be it remembered that thus far the extension of the cables was not considered. They will stretch, the hinge will sink, and the beam not being made for the nearly parabolic curvature natural to the cables, there will result small moments and small shearing forces and a small change of form of the cables, which originally was made parabolic by means of adjustable suspenders. In order to determine those strains, the length of the cable must still be considered, hinges, notwithstanding. H will increase, there will be a sudden tangential break in the middle of the cable, Q will decrease, and the influence of $(1+\varepsilon)$ will have to be considered.

Equation (10), (11) and (12) give these formulæ.

$$\alpha=C_{11}.\frac{1-e^{-\frac{b}{t}}}{e^{\frac{b}{t}}-e^{-\frac{b}{t}}};\quad \beta=C_{11}.\frac{e^{\frac{b}{t}}-1}{e^{\frac{b}{t}}-e^{-\frac{b}{t}}};$$

$$A=C_{11}.\frac{e^{-\frac{b}{t}}-e^{-\frac{2b}{t}}}{e^{\frac{b}{t}}-e^{-\frac{2b}{t}}}-\frac{p}{2Q}.e^{-\frac{z}{t}};$$

$$B=C.\frac{e^{\frac{2b}{t}}-e^{\frac{b}{t}}}{e^{\frac{b}{t}}-e^{\frac{b}{t}}}-\frac{p}{2Q}.e^{\frac{z}{t}}. \quad (14)$$

The discussion of eq. (13) leads to the limiting values of Q. For $z=o$ it is $\frac{k.b^2}{2.H}$ for $z=b$ it is $\frac{(k+p)}{2.H}.b^2$. If the load p progresses beyond the hinge the problem can be treated as if the whole bridge were loaded with $2b(p+k)$ and as if the movable load p were negative, so that for $z=2b$ the value Q becomes $(k+p)\frac{b^2}{2.H}$. For intermediate values Q equation (13.) can be written thus:

$$\frac{y}{t}=\frac{e^{\frac{z}{t}}+e^{-\frac{z}{t}}}{2}=1+\left(\frac{e^{\frac{b}{t}}+e^{-\frac{b}{t}}}{2}-1\right).\frac{p}{2.C_{11}.Q}$$

It is well known that $t.\frac{e^{\frac{z}{t}}+e^{-\frac{z}{t}}}{2}$ is the ordinate p of a catenary proper, where t is the ordinate for $z=o$. The left side of the equation consequently represents $\frac{y}{t}$, and the right side is known, Q being simply assumed. The solution of this equation gives

$$\frac{z}{t}=\text{log. nat.}\left(\frac{y}{t}\pm\sqrt{\frac{y^2}{t^2}-1}\right)$$

and for common logarithms

$$\log. z=\log. t+0{,}362216+$$

$$\log.\log.\left(\frac{y}{t}\pm\sqrt{\frac{y^2}{t^2}-1}\right) \quad . \quad . \quad . \quad (15.)$$

so that for any Q chosen between

$$\frac{b^2.k}{2.H},\ \frac{b^2.}{2.H}(k+p^{\frac{1}{2}}),\ \frac{b^2}{2.H}.(k+p)$$

the corresponding z „ „ „ o, b and $2b$ can be found, so that also t and all other constants are known. The series of z and of other values found should be represented graphically.

All formulæ developed contain the *assumed* value I, which, in fact, is just the quantity to be found.

Differing from the *common theory* of stiffened suspension bridges, it depends, like the moments, etc., on the *permanent* load $2b$. K.

But several examples for varying proportions of $\frac{P}{k}$ and $\frac{H}{2b}$ having been calcu-

lated, certain values of I will be found which can be used towards, at first, approximately assuming I in case of a special project. Calculations of correction are then to follow. The way having been shown in principle, the labor of developing secondary problems is not intended to be done here.

High strains (use of excellent material, excellency of detail design, and superior workmanship combined) are accompanied with great deflections, which, in combination with plate cable curves, reduce the moments of flexure.

It may be desired to build a roadway bridge, which rarely, if ever, will be strained to the limit of the specification. Here the principle of the *stable equilibrium* of the catenary, which has saved so many a weakly-designed suspension bridge becomes useful. For the *limit of flexibility* is indicated, if not already by the chord material *required* on account of wind, by the *greatest admissible grade* of the floor at O′ and O″. This grade at O′ is $\alpha_1 = t\,(A-B)+C$ and at O″ it is $\alpha_{11} = t\,(-\alpha+\beta)-\varphi$. These equations lead to tolerably simple (16) formulæ, if α is only chosen for the case of a half-loaded bridge, because, for this supposition $Q=\frac{b^2}{2.H}\left(K+\frac{p}{2}\right)$. An initial or positive grade at O′ being arranged, a great α_1 can be admitted and chosen, provided, that if the whole bridge is loaded in summer time, there is no visible sagging. To calculate this *camber* the following formulæ may be found useful:

1) The length of the half parabola is:

$$\overset{b}{S}_{o} = b\left(1+\frac{2}{3}\frac{H^2}{b^2}-\frac{2}{5}\cdot\frac{H^4}{b^4}+\frac{4}{7}\cdot\frac{H^6}{b^6}-\frac{10}{9}\frac{H^8}{b^8}+\ldots\right)$$

and for a small variation ΔH

$$\Delta\overset{b}{S}_{o} = \Delta H.\left(\frac{4}{3}\cdot\frac{H}{b}-\frac{8}{5}\cdot\frac{H^3}{b^3}+\frac{24}{7}\cdot\frac{H^5}{b^5}-\frac{80}{9}\cdot\frac{H^7}{b^7}+\ldots\right) \quad (17.)$$

From these formulæ the author has derived others, where ε denotes $\frac{S}{b}-1$ and $\Delta\varepsilon$ denotes $\frac{\Delta S}{b}$, viz:

$$2)\quad \left(\frac{H}{b}\right)^2 = \frac{3}{2}\varepsilon+\frac{9}{10}\cdot\varepsilon^2-\frac{99}{175}\cdot\varepsilon^3+0{,}255.\varepsilon^4\ldots..$$

$$\Delta\frac{H}{b} = \Delta\varepsilon.\frac{b}{H}(0.75+0{,}9\,\varepsilon-0{,}847.\varepsilon^2+0{,}51.\,\varepsilon^3\ldots. \quad (18.)$$

The deepest point of the cable can be found by solving the equation $\frac{d\psi(x)}{dx}=o$. The x which satisfied this condition determines the vertical line passing through the center of all forces π_x acting on the cable. The tangents at A′ and B′ drawn to the curve $\psi(x)$ likewise intersect in a point of this gravity line, a property which can be used to fix it. These two tangents where they are intersected by a horizontal line through the deepest point of A′C′B′ give points of the center lines of all those forces π_x acting on the cable, either to the right or to the left of the deepest point of the cable.

It remains still to illustrate by an example the theory now finished.

Given: Span $2b=1600$ feet, I=180000 square inches × square feet (depth of girders say 40′.) $H = 125' = \frac{\text{Span}}{12{,}8}$. E=12000 tons. Permanent load 3 tons=k per lin. foot. Movable load 1 ton=p per lin. foot.

For half loaded bridge

$$z=b=800',\ Q=\frac{3\frac{1}{2}.800^2}{2.125}=8960\text{ ts.}$$

$$t=491\text{ ft.},\ C_{11}=-C_1=\frac{1}{17920};$$

$$A=-\alpha=-\frac{9.2}{10.6};\ B=-\beta=-\frac{47.14}{10^6}.$$

The moment in the centers of the half beams or for $x=\frac{b}{2}$ and $x=\frac{3b}{2}$ are found ±30800 tons feet, which is at the rate of $\frac{p.b^2}{20{,}3}$. The reactions ± 166 tons for O′ and O″ are at the rate of $0{,}208.b.p$.

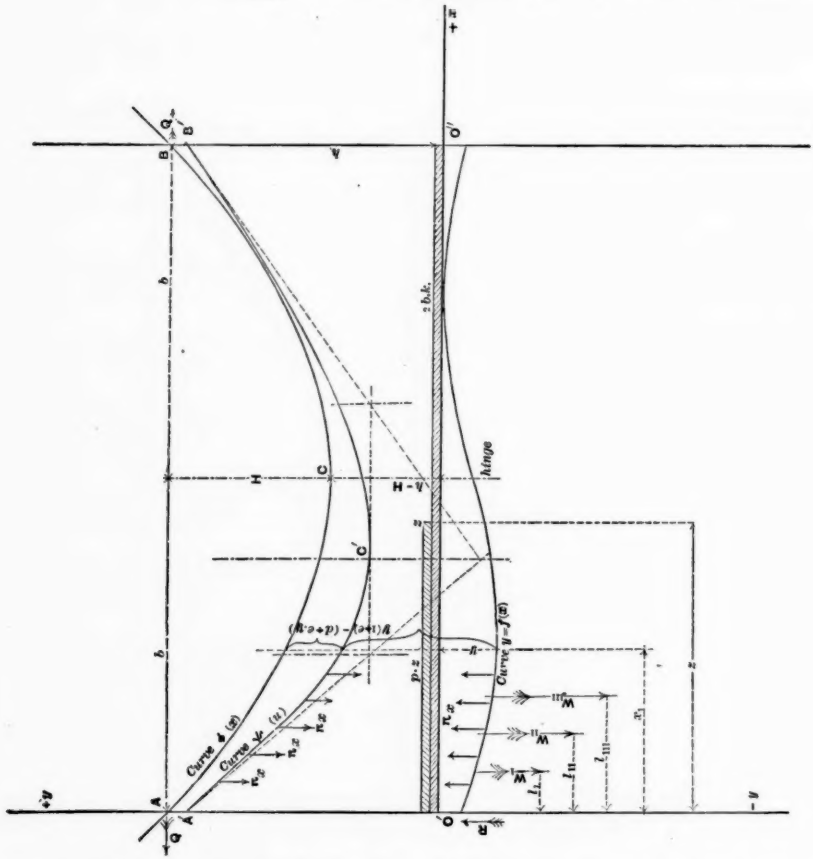
If the bridge had been calculated like a reversed hinged arch, the stiffness due to the change of form of the cables would have been neglected, and if this is termed the common theory the following table may be formed:

	Common theory.	Cables considered.
Reactions	$\pm\frac{pb}{4}=\pm 200$	$\pm\frac{pb}{4,81}=\pm 166$ tons.

Advantage of correct theory 17 per cent.
Moments for

$$x=\frac{b}{2} \text{ and } \frac{3b}{2}\pm\frac{pb^2}{16}=\pm 40000,$$

$$\pm\frac{p.b^2}{20,8}=\pm 30800.$$



Advantage of correct theory 23 per cent.
Strains in chords of beams, tension + pressure tons per square inch 8,888 6,85.

The saving due to distortion of cables is, therefore, not inconsiderable.

If greater flexibility had been desired, the depth of the beam could have been reduced with reduction of I. Shallow girders naturally require greater chord sections.

In case of natural anchorage, H may be reduced with some advantage, leading to a more flexible girder.

The hinge is not the only mechanical arrangement by which the effects of changing temperature can be neutralized.

Fourteen years ago the author, when scientifically occupied with this class of structures, found that continuous ropes led over pulleys attached to cables and floor *continuous self-adjusting suspenders* answer the same purpose. Friction could be considered if desired. Hinged suspension bridges, with beams suspended in this manner, render the theory of reversed hinged arches directly

applicable, and the element of stiffness offered by the cables is really sacrificed. An unhinged beam, with those self-adjusting suspenders, can be built so as to be without negative moments. Its average moment is 0,132 $p.b^3$, whilst for hinged reversed arches it is 0.111 $p\ b^3$, where tension and pressure of each beam are added.

To compensate for this loss the average shearing force of the unhinged beam is only 0,008 $p\ b$, and for hinged beams it is 0,359 $p.\ b.$, in which figures the maximum resulting tension in a member must be considered added to the maximum pressure.

The analysis submitted suggests the possibility *of any degree of stiffness being given* to a suspension bridge.

It is the class of *Partially Stiffened* Regular Suspension Bridges, which the author intended to submit to the consideration of the profession, of which he ventures to hope that—within the practical limits indicated by the premises carefully stated at the beginning—it may become of utility in Bridge Engineering.

WIND PRESSURE ON RAILWAY STRUCTURES.

From "The Engineer."

THE following is the report of the committee appointed to consider the question of wind pressure on railway structures:

To the Right Honorable the President of the Board of Trade.

LONDON, May 20th, 1881.

SIR—In compliance with the instructions from the Board of Trade—a copy of which is given in the appendix—to consider the question of wind pressure on railway structures, and to report to them on the subject, we have made such inquiries and procured such information on the subject referred to as we deemed necessary, and have now the honor to report the conclusions at which we have arrived.

It was necessary in the first instance to ascertain, as accurately as possible from the sources which were accessible to us, what the highest pressures of the wind in this country amount to. With this object we obtained from those observatories and stations where the pressure or velocity of the wind is measured, the statements which we give in the appendix. In order to exhibit the action of the wind during heavy storms, we have also appended lithographic copies of wind diagrams taken by means of self-registering apparatus at Bidston, Glasgow, and Greenwich.

At some of the stations from which we have obtained returns the wind pressures are measured directly by Osler's self-registering anemometers, at others the velocity only of the wind is measured by Robinson's rotating anemometers, the velocity of the wind being taken at three times the velocity of the revolving cups.

For some stations the only published information is the run in miles of the wind during each hour. There can obviously be no more than a general accordance between this and the greatest pressure experienced during the hour. To utilize for our purpose observations taken at stations where the velocity only of the wind is recorded, the records of the Bidston Observatory, where both elements are recorded, have been employed as furnishing a means of connection between the two. In the case of high winds, with which alone we have to deal, it was found that the greatest pressure recorded in an hour was tolerably well proportional to the square of the mean velocity during the hour, and that the empirical formula $\frac{V^2}{100}=P$, where V=maximum run in miles of the wind in any one hour and P=maximum pressure in pounds on the square foot at any time during the storm to which V refers, represented very fairly the greatest pressure as deduced from the mean velocity for an hour. We have accordingly given in the appendix a table calculated from the above formula for deducing maximum pressures from observed velocities.

In addition to the tables obtained from English, Irish, and Scottish stations,

which are those only that are strictly applicable to our inquiry, we give as matter of information a summary of strong winds registered at stations on the Continent and in India.

It will be seen on reference to the tables that the wind pressures vary greatly at different stations. This, no doubt, mainly arises from difference of exposure of the stations to the action of the wind, in consequence of the geographical and local circumstances of their position, but may in some cases be partly caused by differences in the instruments used for measurement. Thus, at Glasgow the highest recorded pressure per square foot is 47 lbs., while at Bidston, near Liverpool, the indicated pressure on one occasion amounted to 90 lbs., and on another occasion to 80 lbs. But the pressures at Bidston seem very abnormal, being much beyond what have been noticed at any of the other stations. The conformation of the ground on which the Bidston Observatory stands is such that the velocity of the wind there might be greatly intensified.

It will be noticed in the lithographs that the records of exceptionally high pressures indicate a very brief duration. From inquiries we have made, we are satisfied that these records are not referable to instrumental error, depending on the recording instrument being carried by its momentum beyond the position of equilibrium, under the wind pressure acting at the moment, but represent a real phenomenon. But whether the exceptionally high velocities to which such pressures are due extend over a considerable space in a lateral direction, or on the other hand are extremely local, is a point on which we have not been able to find experimental evidence.

The differences of the wind pressures observed at different stations led us to consider whether there were any other modes of approximately ascertaining the force of the wind for our purpose. There are many buildings, tall chimneys, shipbuilding sheds, &c, which probably would not withstand pressures so extreme as those we refer to; but in most cases the contour of the adjoining ground, and the obstruction to wind by adjoining buildings, trees, and other surrounding objects, would render conclusions drawn from such cases unreliable. It occurred, however, to us that some useful information might be drawn from another source, viz., from railways themselves.

It is obvious that on existing railways that have been long in use, a series of experiments, if we may apply such an expression to them, have for many years been carried on, for over them trains have been running at all times of the day and night on high and unsheltered embankments, and along other spaces exposed in many cases to very strong winds. Now, a wind pressure varying from 30 lbs. to 40 lbs. per square foot, is sufficient to overturn the ordinary railway carriages that have been in use during the last 25 or 30 years, and we thought it useful to inquire from the different railway companies for cases where railway carriages have been overturned by the force of the wind. The only cases of this kind that have been brought to our knowledge are appended to this report. From the information thus acquired, from the inquiries we have made, and from the consideration we have given to the subject, we are of opinion that the following rules will sufficiently meet the cases referred to us:

(1) That for railway bridges and viaducts a maximum wind pressure of 56 lbs. per square foot should be assumed for the purpose of calculation.

(2) That where the bridge or viaduct is formed of close girders, and the tops of such girders are as high or higher than the top of a train passing over the bridge, the total wind pressure upon such bridge or viaduct should be ascertained by applying the full pressure of 56 lbs. per square foot to the entire vertical surface of one main girder only. But if the top of a train passing over the bridge is higher than the top of the main girders, the total wind pressure upon such bridge or viaduct should be ascertained, by applying the full pressure of 56 lbs. per square foot to the entire vertical surface, from the bottom of the main girders to the top of the train passing over the bridge.

(3) That where the bridge or viaduct is of the lattice form, or of open construction, the wind pressure upon the outer or windward girder should be ascertained by applying the full pressure of 56 lbs. per square foot, as if the girder were a close girder, from the level of the rails to

the top of a train passing over such bridge or viaduct, and by applying in addition the full pressure of 56 lbs. per square foot to the ascertained vertical area of surface of the ironwork of the same girder, situated below the level of the rails or above the top of a train passing over such bridge or viaduct. The wind pressure upon the inner or leeward girder or girders should be ascertained, by applying a pressure per square foot to the ascertained vertical area of surface of the ironwork of one girder only, situated below the level of the rails or above the top of a train passing over the said bridge or viaduct, according to the following scale, viz:

(*a*) If the surface area of the open spaces does not exceed two-thirds of the whole area included within the outline of the girder, the pressure should be taken at 28 lbs. per square foot.

(*b*) If the surface area of the open spaces lie between two-thirds and three-fourths of the whole area included within the outline of the girder, the pressure should be taken at 42 lbs. per square foot.

(*c*) If the surface area of the open spaces be greater than three-fourths of the whole area included within the outline of the girder, the pressure should be taken at the full pressure of 56 lbs. per square foot.

(4) That the pressure upon arches and the piers of bridges and viaducts should be ascertained as nearly as possible in conformity with the rules above stated.

(5) That in order to ensure a proper margin of safety for bridges and viaducts in respect of the strains caused by wind pressure, they should be made of sufficient strength to withstand a strain of four times the amount due to the pressure calculated by the foregoing rules. And that, for cases where the tendency of the wind to overturn structures is counteracted by gravity alone, a factor of safety of 2 will be sufficient.

With regard to the eighth paragraph of the report of the Select Committee on the North British Railway (Tay Bridge) Bill, to which you have drawn our attention, we beg to observe that where trains run between girders they will generally be sufficiently protected from the wind, the degree of protection afforded by the girders depending upon the extent to which the girders are open or close; where the girders are so open as to afford insufficient protection, or where trains run, as in some cases they may do, on the tops of girders, we assume that the engineer will provide a sufficient parapet, but we are indisposed to go further into detail on this subject, as it might tend to stereotype modes of construction which we think is undesirable.

In conclusion we beg to point out that the velocity of wind, like that of every other moving body, is more or less retarded by friction, and will be affected, therefore, by the character of the surfaces over which it has to pass, which may be rough, smooth, or irregular. It will follow, therefore, that, other things being the same, greater velocities will be retained at higher altitudes than at low ones, the wind at higher altitudes being further removed from retardation by friction.

Though we are of opinion that no bridge or viaduct is likely to be built in such a situation as to expose it to wind pressures equal to those which have been occasionally indicated by the disc on the Bidston Observatory, yet even if that were possible, a bridge or viaduct constructed according to the rules we have given would not be subjected to the strains nearly equal to its theoretical strength.

On the other hand, there will be many structures of small altitude or in sheltered situations which never can be exposed to the wind pressure we have assumed, and where the application of the rules we have given would require modification.

Some modification of the rules may also be required in the case of suspension or other bridges of very large span, but such cases will be of rare occurrence, and we recommend that they should be specially considered when they arise.—

We have the honor to be, Sir, your most obedient servants,

JOHN HAWKSHAW,
W. G. ARMSTRONG,
W. H. BARLOW,
G. G. STOKES,
W. YOLLAND.

We, the undersigned, concur in the above report so far as it goes, but we think the following clause should be added, viz:

The evidence before us does not enable us to judge as to the lateral extent of the extremely high pressures occasionally recorded by anemometers, and we think it desirable that experiments should be made to determine the question. If the lateral extent of exceptionally heavy gusts should prove to be very small, it would become a question whether some relaxation might not be permitted in the requirements of this report.

W. G. Armstrong,
G. G. Stokes.

The following is the table above referred to as given in the appendix:

Wind Velocities and Pressures.

Maximum hourly run of the wind in miles.	Maximum pressure in lbs. on the square foot.	Maximum hourly run of the wind in miles.	Maximum pressure in lbs. on the square foot.	Maximum hourly run of the wind in miles.	Maximum pressure in lbs. on the square foot.	Maximum hourly run of the wind in miles.	Maximum pressure in lbs. on the square foot.
40	16·0	56	31.4	71	50·4	86	74·0
41	16 8	57	32·5	72	51·8	87	75·7
42	17$\frac{1}{2}$6	58	33·6	73	53·3	88	77·4
43	18·5	59	34·8	74	54·8	89	79 2
44	19·4	60	36·0	75	56·2	90	81·0
45	20·2	61	37 2	76	57·8	91	82·8
46	21·2	62	38·4	77	59·3	92	84·6
47	22·1	63	39·7	78	60·8	93	86·5
48	23·0	64	41·0	79	62·4	94	88·4
49	24·0	65	42·2	80	64·0	95	90.3
50	25 0	66	43·6	81	65 6	96	92·2
51	26·0	67	44·9	82	67·2	97	94·1
52	27·0	68	46·2	83	68·9	98	96·0
53	28·1	69	47·6	84	70·6	99	98·0
54	29·2	70	49 0	85	72·2	100	100·0
55	30·2						

THE PROPOSED INDO-MEDITERRANEAN RAILWAY.

By COMMANDER V. LOVETT CAMERON, C.B., D.C.L., R.N.

From the "Journal of the Royal United Service Institution."

The subject to which we have to turn our attention to-day is one of vast importance to this country, and since the days of General Chesney has never been lost sight of by some among us, although the startling occurrences of modern history have often caused the general ideas of the English nation to be turned in other directions.

The subject of railway communication between the Mediterranean and Persian Gulf has already been discussed here, and it is with feelings of diffidence that I venture to give my opinions on the subject, knowing that every authority hitherto has differed as to the line to be followed, and that I myself agree with no one as to the precise route, though I do in the main idea that it is of the utmost importance to us as a country strategically, commercially, and politically to connect the Persian Gulf and the Mediterranean Sea, by a line of railway which ultimately may be prolonged so as to join our Indian railway system.

I will now describe the country I traveled over, having a special reference to railway construction.

From Cyprus I went by steamer to Beirut, and then when we had collected our baggage animals, we crossed the Lebanon into Cœle Syria, by the French road between Damascus and Beirut. Turning northwards at Shtaura, we went up the valley between the Lebanon and Anti-Lebanon to Homs. At Homs we were assured that the best pass between the sea coast and the fertile plains of the interior lay between it and Tripoli. I had, before this, the intention of going

to the sea coast near the mouth of the Nahr el Kebir, and northwards along the coast to Latakia, in order to look for a practicable pass in the mountains; this news determined me to go to Tripoli, and thence, if it proved correct, work back again to Homs.

A Zaptieh was given us as guide, who was said to know the best way, but who took us the shortest way, and the one now followed by many of the caravans; this road, however, did not seem very promising, as the plains which fringed the sea were separated from the plateau we had been crossing by an almost precipitous descent, down which wound a narrow, slippery, zigzag path. But when we arrived at Tripoli, we were told by our Vice-Consul, Monsieur Blanche, who has spent many years there, and is well acquainted with the topography of the surrounding country, that we had been brought the shortest line, but not the best, as by going round a little way and following the line of the old Roman road, we should find an easy route from the coast plains into the interior.

Tripoli is now a place of less importance than either Beirut or Iskanderun, but her position at the mouth of the most practicable pass into the interior insures for her a most important future. She was in ancient times a larger and richer town than any of her modern rivals, whilst her predecessors, Arvad of the Phœnicians, now the desert Island of Ruad, was a competitor with Tyre.

During all times but the most modern, the route which we took from Tripoli back to Homs was the most important of all those between the coast line and the interior. The Egyptians in their wars against the Hittites made use of it, and the foundations of Kalaat Ibn Hosn, a fortress which has played a part in many a forgotten war and campaign, show traces of their handiwork. As the Egyptians invaded the Hittites before the days of Moses, this position has long been regarded as one of importance. The two wadys by which the higher level is reached join together very curiously in the center of their length; and whilst below this junction one is too narrow and has its sides too precipitous to be of use for carrying a road up it, above this point it is wide and easily ascended, whilst precisely the reverse is the case with the other.

The Romans, in forming their road into the interior, took advantage of this peculiarity, and in many places their ancient causeway might be utilized in the construction of a railroad, although, of course, in some cases the gradients would be too steep. From the watershed (highest point 1,100 feet) at the head of these wadys a gentle slope leads to the fertile plain of the Lesser Bukéa (level 720 feet); this crossed, a second line of hills has to be crossed, but for only about 3 miles did any difficulty present itself, and that might be easily overcome. In crossing this plain, 180 feet was risen almost imperceptibly, and then for the first 3 miles to Hadeedy, 300 feet more would have to be ascended, or a gradient of 1 in 60. From Hadeedy 350 feet more would have to be risen to arrive at the highest point between Homs and the sea. Here the steepest gradient would not be above 1 in 80. Some old Roman bridges show that once there were rivers running on this piece towards the Lake of Homs, and some provision would have to be made for the flood waters, and at one place near Jisr Achan (Bridge of Achan) it might be better to cross a small valley by an embankment and cutting instead of making a *detour* to avoid it, or by using heavy gradients. From the highest point a very easy slope brings the line down to the Orontes, which here can be easily crossed, and the town of Homs is at once reached. Homs is even now a place of considerable importance, and is well situated as being a point whence level roads diverge towards Damascus, Baalbec, and Hamath.

Homs is also on the direct route to Palmyra if at any time the Palmyrene Railway should be decided upon, and, therefore, is destined to be one day a great junction station.

Any body of troops concentrated at or nears Homs, and having railway communication with Tripoli, would command the whole of Syria behind the ranges of the Lebanon; grain, cattle, and sheep are abundant, and addition to the water supplied by the Orontes and its affluents, wells of no great depth (about 30 or 40 feet) might be easily made where required.

If ever the Suez Canal is to be threat-

ened by an army marching from Asiatic Turkey, that army would have to pass through the districts around Homs, and a force there might easily be reinforced from Cyprus if the railway to the coast be constructed.

There are the remains of large barracks which were constructed by the Egyptians during their occupancy of the country, and although now destitute of doors and windows, and looking in a ruinous and dilapidated condition, still they were so well built originally that they might easily be put in repair.

The whole country is so flat that there would be no difficulty in moving troops in any direction, and if wheeled vehicles were imported, there is nothing to prevent their being used. Mules, camels, and horses are plentiful, and if the friendship of the Aneyzeh Arabs were secured, an almost unlimited number of camels might be procured at a very cheap rate.

From Homs to Hamath, with the exception of crossing the valley of the Orontes, at Rusta, there is scarcely any work to be done, and the whole country is fertile, and, under a settled and just Government, the population, at present huddled together miserably in the towns, could be profitably employed in agriculture.

The Orontes at Rusta runs in the bottom of a gully about 120 feet below the general level of the plain; here was once, as at all other important points, a Roman fortress which defended the passage of the river. The southern side of this gully widens out and slopes gradually just to the west of the village, and an easy gradient would bring us down the first 60 feet from whence a viaduct of about 300 yards in length would take us to the north of the river. Here the line might either wind round the curve of the bluff, or a cutting 60 feet deep at the commencement, running down to nothing at the end, be made for a distance of half a mile.

After this, as far as Hamath, the line might be laid on the surface, only leveling, ballasting and drainage having to be attended to.

At Hamath, the Orontes would have to be crossed again for the third and last time, but as its valley widens out around the town, no difficulty would be met with here beyond that of bridging the stream.

Hamath is one of the most ancient towns now existing in the world, and is constantly mentioned in the Pentateuch and other historical portions of the Bible. When we were there, it was crowded with Circassians who had been deported from European Turkey, and who here, as elsewhere, were a very great source of trouble to the authorities. Here, also, as at Homs, are old barracks which might be repaired, and the khans or caravanserais might also be used for the accommodation of troops. The Aneyzeh have more dealings with the Governor (Mutesarif) of Hamath than they have with the Kaimacan at Homs, and perhaps, therefore, this might be a better spot to collect camels from them. The land which is irrigated by the Orontes is most fertile, and if modern systems of raising and distributing the water were used instead of the cumbrous and clumsy wooden wheels and antiquated aqueducts, it might be enormously increased in extent and productiveness.

At Hamath, the valley of the Orontes is gradually left, and the whole distance thence to Khan Shaykh Khaun is almost perfectly level, the only works necessary being bridges over three river beds, which in the rainy season carry the flood water from the higher land on the east, down to the Orontes.

The khan here is an old building, at all events, dating from the days of the crusaders, and would afford shelter to a large body of men and stores, and would be perfectly defensible against everything except artillery, and the outer walls are so thick and solid that it would require a long-continued fire from the heaviest field guns to breach them. Water is here obtained from wells and is not very good; if the wells were bored deeper the supply would be more abundant and most probably purer. An old stone-lined tank lies outside the south-east corner of the khan, but it has been neglected and is now useless; doubtless it might easily be repaired, and if care were taken, every year's rains would fill it and afford a supply for the months of drought.

At Khan Shaykh Khaun, the hills which form the edge of another plateau are reached, and an easy ascent leads to

their summit. An average gradient of 1 in 120 would, by following the curves of the hills, bring the line to the highest point between Khan Shaykh Khaun and Marah. Marah, which lies in a slight valley, may be reached by a gradient averaging 1 in 250, and thence again the level of the plateau may be equally easily reached. Though anciently all this country was covered with large and wealthy towns, it is now quite bare and deserted. Immediately round Marah are vineyards, and wheat is cultivated, but the people live in dread of the Bedouins, and dare not go far afield. The khan here is even larger than that at Shaykh Khaun and was repaired by Ibraham Pasha. It might easily be converted into very good barracks, and there are the ruins of an old Genoese castle which might also be utilized. The town itself is mean and miserable, though if the Kaimacan was to be believed it was very prosperous and exported large quantities of grain and raisins.

Some idea of the want of order that exists about here may be drawn from the fact that some Bedouins made a dash right into the khan, and drove off some mules, though their owners outnumbered them by more than two to one, and even when the Zaptieh were appealed to, they refused to follow the raiders.

From Marah a slight rise brings one again on to the higher level, which if it were not for the purpose of collecting the traffic of the town and district, need not have been quitted; thence to close to Aleppo, the whole road is practically a level one. Around Marah are an enormous number of ruins, dating from the latter days of the Byzantine Empire; these show that once the whole of this country was densely populated; and as we went along we saw several small towns and villages besides the important one of Idlib, and numerous villages. The smaller towns and the villages are now, or were when we passed by, greatly troubled by the Arabs. Some years ago the Arabs of the desert used to levy blackmail from their inhabitants, who are also Arabs, and in return used to prevent the Turkish tax gatherers from collecting the taxes. The then Wali of Aleppo, in order to meet this difficulty, organized a corps of rifles, mounted on mules, who were able to keep the Bedouins in check, and the peasantry paid taxes to the Turks instead of blackmail to the Aneyzeh. The needs of the Porte during the Russo-Turkish war led to this corps being sent as infantry to join the army in the field, and now the Aneyzeh have extorted blackmail, and what they are pleased to consider the arrears, and also allow the taxes to be collected, the peasantry, therefore, are in greater straits than ever they were. At Khan Tomaun, near Aleppo, the caravan road from the south leads over some stony hills, but by following the valley of the River Halep, an easy and level road may be found.

Aleppo in ancient days was the principal emporium of Eastern commerce, and at present it is calculated that 80,000 camels are employed in her carrying trade, 10,000 of which are to be found between Aleppo and Iskanderun.

The barracks built by Ibrahim Pasha are capable of holding 10,000 troops, and there is a very fair military hospital which, at the time of my visit, was occupied by deported Circassians. The khans, which are numerous and spacious, would also lodge large numbers of men, and there are many large houses belonging to merchants and private individuals, as well as arcaded bazaars, which might all be utilized in the case of necessity. The citadel is in a very ruinous condition, but a great portion might be roughly repaired and rendered of use.

Owing to the commercial importance of Aleppo, and the number of pack animals constantly passing through, transport and supplies for a very considerable body of men might easily be collected there, and as it commands the routes to Syria, Iskanderun, Aintab, and those of the Euphrates Valley and Mosul, it will always be a place of the greatest strategical value.

If the line were commenced, as most people consider it should be, at Seleucia or Iskanderun, very much greater engineering difficulties would have to be encountered than by the route I have traced out, the fertile regions around Homs, Hamath, and Idlib would be left unprovided for, and if an army from the north or east had managed to possess itself of Aleppo, there would be no means of opposing its advance on the Suez Canal, through Syria and Palestine, whereas, even if Aleppo should be in an enemy's hands, we could by the line I advocate pour in troops and supplies from Tripoli

on Homs, and there make a second stand to cover our great waterway to the East.

Proceeding eastwards from Aleppo as far as Tedif, a small town, four miles from Bab, where there are barracks, which might be made to contain 2,000 men, the ground is quite level, and then some gentle undulations would have to be crossed before arriving at Hierapolis (Mombedj). Here are settled some Arabs, who claim to belong to the great Aneyzeh tribe, and who are especially friendly to the English, as are all the inhabitants of the surrounding country, except some of the deported Circassians, who are enemies to every one, including themselves. These Arabs would be of use in constructing a railway, and from them and their relations in the desert might be gathered a number of hardy horsemen, who, with a little training and teaching, might render invaluable service in war time as scouts and also for harassing the convoys of an enemy.

From Mombedj the most level line to the Euphrates would be to the embouchure of the Nahr Sadshur, where a bridge might be easily constructed at a camel ford; the Romans indeed bridged the river a little lower down and where the water is deeper, and I can conceive no difficulty to a modern engineer in constructing a bridge across a river where the greatest depth of water would be four feet, and where the foundations of many of the piers might be made on islands and shoals which are dry for the greater portion of the year.

When the river is crossed, some insignificant hills have to be passed through, and then the plain, level as a billiard table, on which are situated Haran and Urfa, is reached. Haran is now only inhabited by a few sedentary Arabs, but there are the remains of the Roman camps and also of the castle, church, and fortifications built by the Crusaders under Baldwin and his successors, Counts of Urfa.

Urfa, itself, is a place by which a great deal of trade passes, being situated at the foot of the hills over which the road to Aleppo via Bir-ed-jik runs, and most of the traffic between Aleppo and Mosul and Diarbekr passes by. Monsieur Martin, the French Vice-Consul, who owns a considerable amount of land in the neighborhood, and also buys grain in large quantities, told me he often dispatched over 600 camels to the coast, loaded with wheat, in one day, and sometimes had sent off 1,200 in one caravan.

There are some very good barracks in good repair, which would hold three or four battalions of infantry, and the khans and the Government buildings at Serai might also be utilized. The old walls round the town are, in many places, in fair condition, and on the sides towards the plain there is a deep ditch, almost a ravine. The place might easily be made defensible against troops unprovided with siege artillery.

Crossing the plain from Urfa, and keeping under the mountains which form the boundary between the Northern Mesopotamian Plain and the high lands of Armenia and Kurdistan, we should for a short distance have to pass through low and rounded hills, where some slight works might be necessary; but once these hills are passed, an unbroken plain extends away to the east of Nisibin.

At the southern end of the Karaja Dagh there is a break in the line of mountains, and an easy road or a branch line, might be made to the important city of Diarbekr.

Diarbekr is still enclosed within walls, of what date it is difficult to say, but the curious way in which carved and sculptured stones of different periods are placed in juxtaposition tells something of the many vicissitudes through which the city has passed.

Of old the capital of Armenia, it even now is one of the most important points in these regions. When the railway through Anatolia from the Bosphorus is constructed, Diarbekr is sure to be one of the places through which it will pass. It commands the passages of the Tigris, and an army corps having its head-quarters at Diarbekr ought to command the upper waters of both the Tigris and Euphrates, and be able to prevent an army advancing from Kars and Erzeroum, on Syria or Baghdad, from utilizing these rivers for the purposes of transport. Diarbekr is even of more account in the present day because of her bridge than because of her walls and ancient churches and mosques. The same story may be read in the stones of the bridge as in those of the walls, and its earliest parts

most probably date from before the Christian era.

Returning to our main line, we soon pass under the famous town of Mardin, perched up in the mountainous crags that overhang the plain like the eyrie of an eagle. Mardin is the one place which held out successfully against the elsewhere-victorious arms of Timour.

From the ruins of the old citadel, a most extensive view is obtainable, and the range of the Sinjar hills which extend from Mosul to near Palmyra for some of the distance, being known as the Abdul Aziz Mountains, bound the southern horizon. Mardin dominating the plain in the manner it does, and being easily capable of being rendered impregnable, would form a most important position in the defence of the line, and no army advancing from the east could dare to pass such a post unless it were masked by a force far superior to its garrison; and, even then, as to surround Mardin is almost impossible, a daring body of cavalry having it as their *point d'appui* might so harass the communications of troops advancing either from the north-east or east, as to cause serious anxiety to their commanders.

South of Mardin, around Ras el Ain, are the settlements of a number of Circassians, and beyond them the mountains of Abdul Aziz and the tribes of the desert. Though the Circassians are as bad as their fellow-countrymen elsewhere, still they have some good military qualities, and proper discipline might furnish a valuable body of cavalry. The Arabs, trained in ghazous and raids, and living under the open Heaven, have their perceptive faculties sharpened to the utmost, and would be most invaluable as scouts and to collect information. A man who can steal a mare from the center of the encampment of a rival tribe, though crowded with dogs and cattle, could penetrate into any camp of ordinary soldiers, and bring away in his memory every material detail. On both sides, therefore, the holders of the line, if they also have had the tact necessary to make friends with their neighbors, would be possessed of local means of defence against any enemy.

After leaving Mardin we pass by the towns of Dara and Nisibin, ancient rivals and frontier posts of Imperial Rome, and her constant enemies, the Persians. Both are only now small places of no great importance; but, lying as they do in districts of great fertility and well watered, there is no doubt that they will, when once more in communication with the outer world, show signs of renewed vitality. Though at the time we were at Nisibin there was sickness there, all the surrounding districts were perfectly healthy.

From Nisibin we at first went along a plain, about which were dotted several villages and the ruins of more: many of the latter were quite of recent date; indeed, the Christian Chief of Asmaur told us that ten out of twenty villages inhabited by Chaldean Christians had been destroyed during the previous twelve months. After passing this district around Asmaur, we went across a country once inhabited and covered with towns, but now only affording pasture to the flocks of nomad Kurds or Bedouins, until close to the Tigris just above Mosul.

The whole of the country traversed between Urfa and Mosul was once populous, prosperous and well cultivated, and it is only owing to the apathy of the inhabitants that wells and watercourses have been allowed to become choked up, and forests destroyed, so that what was once a smiling garden is now in parts, for some months of the year, a parched and arid waste.

In the wars between the Parthians or Persians and the Romans, armies, often consisting of over a hundred thousand men, traversed this country in every direction; and if what history relates of luxurious camp-equipage of these ancient warriors be true, they must have been even more hampered and encumbered by non-combatants and beasts of burden than any modern force, and must have everywhere found grain, water, and forage in abundance. As matters are at present, it would be a difficult matter in extra dry seasons to march a force from Urfa to Mosul by this line, though with very little trouble in the construction of wells, there would be no difficulty whatever. As far as I could judge from the appearanae of the land and the dip of the strata, in no place would it be necessary to go deeper than from 70 to 80 feet, and usually a much less distance, before

reaching water; the rock to bore through would be a soft and friable limestone, easily worked, but possessing quite sufficient cohesion for the sides of wells to stand without any artificial means of support.

Of course, if a railway were made here the first thing to be done would be to dig wells. A certain number of laborers might be found on the spot; but a Christian merchant and contractor told me he could place 4,000 families, or about 10,000 working men, at any place or places between Urfa and Mosul, and engage to keep them supplied with food whilst they should be employed. The cost of such labor, including food, should not be more than 1s. 6d. a man a day. The same merchant could also provide, more easily than any one else, carriage for stores and materials, and was so taken with the idea of a railway passing near him, that he said he would take £30,000 in shares, if it ever were made.

Mosul is now surrounded by a wall, which was built a few years ago to protect it from the raids of the Shammar Arabs, but which would be a snare and delusion to its defenders, as it is so badly traced that long stretches of the banquette can be enfiladed by people lying behind the earth thrown up out of the apology of a ditch which surrounds it.

The barracks and Government buildings are outside the town, and might easily be made available for four or five thousand men. On the eastern side of the Tigris the mounds of the ancient Nineveh afford admirable opportunities for the construction of a *tete du pont* to protect the bridge across the river. Mosul commands a route to the northeast and east leading to Teheren and the Caspian, also one to Diarbekr and Jesireh, the great wool mart. Near Jesireh are valuable coal mines which, of course, would prove of great importance, and it would be a question to discuss how best to link them to the line at Mosul.

At Mosul the question arises as to whether it would be better to cross the Tigris there, or continue on its right bank as far as Baghdad. If the river is crossed at Mosul, a very much more difficult country would have to be traversed, two other rivers, the Greater and the Lesser Zab, would have to be crossed, and the railway would be open to raids on it from the east. If the right bank is followed, the railway is protected for its whole length by the river, and easy country is passed through, and the distance is much less than if the railway passed by Erbil and Kerkuk, the only real advantage claimed by those who advocate going to Baghdad from Mosul by the eastern side of the Tigris. Another advantage is claimed, viz., that on the east of the river the railway would be more defended from the Bedouins; but those who raise this chimerical objection forget that any of the railways proposed in those regions would be more or less exposed to such a danger if it did exist, and that the populations to the east of the river are just as likely or more likely than the Arabs, to damage a railway, whilst the Shammar Arabs, through whose districts the line on the right bank would principally run, are at present in alliance with and subsidized by the Turkish Government.

Between Mosul and Baghdad there are no difficulties worthy of the name, and if a railway were constructed and irrigation and agriculture encouraged, the country would once again become densely populated.

Baghdad is one of the largest towns of the Asiatic dominions of the Sultan, and is especially important to us as being so intimately connected with our Indian possessions. As the seat of the Caliphs, Baghdad, and before it the cities of Seleucia and Ctesiphon, was once the center of the civilized world, where learning and arts, commerce and science, had progressed further than they had in Europe, and though it can never be expected that she will regain all her ancient wealth and prosperity, still it may be confidently said that when the principal city of the richest province of Asiatic Turkey is once more in easy communication with the rest of the world, she will again become one of the greatest of marts.

Steamers from Baghdad to Bassorah are now running, two English and six Turkish, besides which the Bombay Marine steamer "Comet" is at the disposal of the Resident. The difficulty of the navigation is such that it is rare indeed that the passage is accomplished in less than four days, and the cost of the double transhipment of goods, and the delays

consequent thereon, would go far to neutralize the advantages gained by the railway. Baghdad can never, therefore, be a terminus—an important station she is and always will remain. As Baghdad cannot be a terminus, where shall we find one? Kweyt and Bassorah have both been proposed; Kweyt is disposed of by the fact that it is on the wrong side of the Persian Gulf, and therefore when (as without any spirit of prophecy it may be asserted will be the case) the line is continued on to meet our Indian system, the Kweyt portion of the line would only serve a very small and very local traffic. Bassorah is debarred by the fact that the land around it is so low and so easily flooded, and is so liable to have channels cut in all sorts of unforeseen directions by these floods, that the construction of a railway to that place would be costly in the extreme, and its maintenance scarcely practicable.

Where, then, shall we look for our temporary terminus? At Abushire, "the father of ports." I know the portion of the line I am now going to advocate has been condemned by Mr. Blunt, who traveled with his wife, Lady Anne, from Baghdad to Abushire (Bushire) by land, and who I have heard assert that it would be utterly useless to construct a railway there, that such a railway would be of no value and never pay. With all respect for Mr. Blunt I venture to differ from him, notwithstanding his personal and local knowledge of this portion of the line. A very large trade between India and Baghdad already exists, and even now people from Bushire go to Baghdad by sea in large numbers. The holy places of the Shiah Mahommedans attract enormous numbers of pilgrims; Samara alone is visited by upwards of 30,000 every year, and many a pious heir brings the corpse of his father to be interred in the holy soil. This traffic, and the trade resulting therefrom, would all be taken by the railway.

He says that the country is uninhabited and uncultivated, but complains of the number of rivers he had to cross. A river properly used in these latitudes means wealth untold to the lucky persons who can avail themselves of its waters, and if these countries are not prosperous at the present moment, it is not from any physical incapability or on account of soil or climate, but on account of the blighting misrule under which they have groaned for centuries. These very rivers, especially the Karun, will be our greatest friends, and will enable us to transport our *matériel* to the required positions at a minimum of time and cost. From Dilam, where the coast should be reached, the shores of the Persian Gulf should be followed as far as Bushire. Here for the time the railway might rest, but as the Eastern Question develops, so will the continuation to Kurachi and a line from Mosul to Herat and Kandahar become more and more plainly necessary. As we have to consider, in a line of this sort, its future developments, and as no doubt it is destined to form one system with the railways of India, it is right and fitting that the guage should be that of the trunk lines of the Indian Empire. One great Power, in her consciousness of the danger of more civilized nations penetrating her shell, has deliberately broken the guage at her frontiers; we should benefit by the lesson thus taught, and in constructing these lines make them more readily available to ourselves, to whom they are of most importance, than to possible rivals.

Bushire and Tripoli, at a comparatively small expenditure, may be made into good harbors and quays, and wharves could easily be constructed at both places so as to avoid the necessity of using cargo boats.

I have thus endeavoured to trace the course of what I hope may be the first section of the Indo-Mediterranean Railway. Instead of its being a rival to the Suez Canal it would prove a most important ally, and would enable us to thwart any attempt on our present lines of communication with India.

By steamers from our now first-class port of Kurachi to Bushire, troops could be conveyed from our Indian possessions to the railways which would place them in the commanding positions in the battle-fields of Armenia, there to find themselves met by their brothers in arms arriving from Cyprus and other *places d'armes* in the Mediterranean.

At Cyprus we have a port, Flamagusta, where ironclad ships could lie in perfect safety only six hours distant from the terminus of the railway, and from Cyprus

we could at a moment's notice transport men to stop revolts, barbarities, and atrocities in the greater portion of Asiatic Turkey. The knowledge that we could do so would prevent horrors such as have, in Bulgaria and Roumelia, disgusted the civilized world, and which still leave their poisonous effects behind them.

If the Suez Canal should ever be blocked (a matter by no means difficult of accomplishment), or Egypt and the Canal fall into the possession of a hostile Power, it is to the Indo-Mediterranean Railway that our navy and army would have to look for assistance in maintaining our wonted communications with India, or to recover our control over the great highway for ships.

I fear this has been a long and wearisome paper for those who have listened to it, but railways do not belong to the days of romance and comedy, but to the work-a-day world of the 19th century.

Lieutenant Colonel BATEMAN CHAMPAIN, R. E.: It seems to me that this question is one of very great importance, and that you. Sir, and every one present will be glad of any light, however small, that can be thrown on the general question raised by the paper to which we have listened. I have twice ridden up the Tigris Valley from Baghdad, once to the Black Sea, and once to the Mediterranean, along a great part of the road that has been so well described by Commander Cameron this afternoon. I merely mention the fact of my having personally visited the country as an excuse for my venturing to say one or two words. If Asia Minor or Mesopotamia belonged to the British Government, I, for one, would consider it our bounden duty to make roads and railways in every direction. I agree with Commander Cameron in thinking that it is one of the richest countries in the world, and every one knows that it has been suffering from ages of misgovernment. But I would, as far as my own opinion goes, protest, as strongly as I have done before, against the idea that the Euphrates Railway or the Tigris Valley Railway would be a really good and sound means of military communication between England and India. Of the two, decidedly I would prefer the Tigris Valley, but I object to the whole scheme, on grounds which I will presently state. I prefer the Tigris route because along the Tigris there are towns and places of commercial importance, whereas on the Euphrates there are none; between Biredjek and Bassorah there is hardly a town or even village of any note. On the other line there are Diarbekr, Mosul, Arbil, Kerkuk, and Baghdad. Those places could, no doubt, well support a small local railway. But if the railway be constructed in a costly manner, as a means of military communication, it would never pay, and consequently I believe would fall into slovenly management, and if ever it were worked would prove a thorough failure. I believe no through traffic would pass over it, even in time of peace, as no merchant in the world could afford to employ that route. Suppose the line were continued as far as the head of the Persian Gulf, the transhipment there and at the other side would cost an enormous amount of money, and seeing how little is paid for freights now-a-days to and from India, it is absurd to suppose that any kind of merchandise would pay the enormous extra cost that would be entailed simply to gain four or five days, and I do not think more would be gained in practice, because the line could not be worked at express speeds. Scarcely any through travelers would use the line. The climate is for three or four months in the year exceedingly pleasant, but any one who knows what it is to be cooped up for three or four days in a railway carriage, even in these temperate climates, will admit that such traveling is exceedingly uncomfortable, even when one has a whole compartment to one's self. But to box up twelve or thirteen soldiers in a third-class carriage, and carry them through that arid, dusty country, would be nearly impossible for nine months of the year. The health and strength of the men would be destroyed unless you could break the journey two or three times, and in that case you would lose all the advantages this route professes to offer. The thermometer has been known to register at Bassorah as much as 126° in the shade—an excess of heat which could not be borne by men packed closely together. On board ship great heat is bad enough, but it is supportable. Life on the Red Sea is, no doubt, at times unpleasant, but to be

cooped up in a railway carriage for a long journey like that, from the Mediterranean to the Persian Gulf, would be intolerable. The worst part of the whole journey to India is thought by many to be the railway from London to Brindisi. Crossing the Isthmus of Suez is also generally looked forward to with a certain amount of distaste, and the bother of disembarking and re embarking at Alexandria and Suez is very great. That being the case, I assert that the line under discussion, unless it is to depend entirely on its local traffic, cannot be pronounced a desirable undertaking. With regard to going down the river from Mosul, I am certainly inclined to think that the left bank is the proper one to follow; you traverse a much richer country and pass through several important towns. As to the Arabs and Kurds, though I have nothing to say against the former, still they are a difficult people to control, and nobody can calculate on making the camel journey from Baghdad to Damascus without being robbed; but, generally speaking, any one can ride, as I and others in this room have done, through the Kurd country without molestation, and that is the line which has always been chosen by the Turkish Government for its post road, its telegraph, &c. Finally, I cannot agree with Commander Cameron in his remarks on the eligibility of Bushire as a port. No ship of any size, drawing more than twelve or fourteen feet of of water, can get within three miles the place.

Mr. Scott Russell, F. R. S.: As I have had the pleasure, I may call it, of examining that country with the view of carrying through it a railway which might be commercially profitable, and which it might be strategically wise for England to promote, I will venture to make a few remarks upon this paper, and I will call attention to the necessity in dealing with this subject of taking three quite distinct views. First, you must consider the relations of this railway to through communication through Europe with the Indian Empire. You must then consider it with special relation to English interests. And, lastly, you must do what is perhaps still more difficult for us to do, consider it with a view to developing the interest and the prosperity of the countries through which it passes. I mention all this, which appears a complicated problem, because I was compelled to think of it, whether I chose or not, in all these different aspects. I was asked by the representatives of several Governments to tell them what, after examination, I considered the best route from Belgrade to the Persian Gulf. As an Englishman my feelings did not stop there. We English have too many friends in India not to think, when there is any talk of such a communication, how we can easily and most conveniently visit our friends in India or have their visits paid to us, and, therefore you will pardon me when I say that I could not make up my mind to stop at the Persian Gulf, and was obliged to go on until I got to Kurachi. I examined that line (1) as a professional *engineer*, who, in his early life, was engaged in the construction of railways, before he began to construct steamships. (2) After that I was obliged to look at it as an *Englishman*; and (3) strategically. I, therefore, went to our most distinguished strategist at the War Office, Sir Henry Storks, who I am sorry to say is now dead. He was good enough to initiate me into all his views with regard to the strategical value, advantages and disadvantages of certain lines of railway in Asia Minor, in Turkey, and in Persia. I discussed with him the whole of these questions, and received from him the best possible advice. You may think it curious that I should have got all this advice from the various States who were interested in this railway, but I tell you that there was no merely mercantile object in view; it was entirely an international object; and for that purpose I made the investigation. I therefore looked at this railway, which is now proposed, and which, if you please, I will call the "Mediterranean and Persian Gulf Railway," in its relation to the great through international communication, and I found that, although it might be very good as a local railway, yet, as an element of through communication, it was not all that I could desire. With regard to Commander Cameron's special line, there are qualities in that line which I have not seen in any others, and they are these: that the line he proposes, although not of high value as a thorough independent line, would, to a considerable extent be a better ad-

junct to a general international communication than any of the other lines I have seen proposed, called "Euphrates Valley Lines." In the system of international railways, which I was compelled to examine, we came to certain points from which we sent off branch lines exactly resembling those laid down by Commander Cameron. Allow me to say, further, that you must consider this international railway in a strategical point of view. I had the advantage of the assistance of one of the most distinguished railway authorities in England, and a Royal Engineer of great eminence, and also of the assistance of an engineer officer in the service of the Turkish Government. I had all the plans and surveys of the different Governments of Europe communicated to me, and where I did not find the surveys satisfactorily executed by other people, I went personally, accompanied by the friends I have named, and examined those districts with reference to their convenience and practicability. I can quite confirm what Commander Cameron has stated, that those ways up to the high level of the central plateaus, which have hitherto been called impracticable and have been avoided, are ways which are easily practicable, just as the line which he has selected is, and can easily be reached and passed by the ordinary standard of steepness of railway which we are accustomed to use in England. Therefore I am satisfied that on no merely engineering ground can Commander Cameron's selection of line be considered at all an impracticable or an unwise one. There is one point, however, on which I rather agree with Colonel Champain, that is, I do not like that line from Mosul to Baghdad. I will not go through my reasons, there are very many, but I do not like it, and I would prefer his Tigris Valley portion for that part of the line, instead of Commander Cameron's. I do not know what his reason is, but my reason for preferring the Tigris is a very strong one. I think it agrees with Colonel Champain's. I would entreat all those officers and members of this Institution, who interest themselves on this subject, not to commit themselves to any particular portion of this or other lines, until they have considered it in the larger view of a through route to India, and I would also entreat them to take another view, which does not seem to have been taken. If in each of those countries you have to pass through, you will begin by laying out a system of railways, designed in the first instance for developing the wealth and commerce of these individual countries, and if you will first of all study the structure of the mountains and the valleys of that country, with a view to the formation of paying local railways, you will find, when you have laid out a systematic group of railways for Turkey and Asia Minor, and for Persia, and when you have systematically connected our Empire in India through Afghanistan and Beloochistan with Persia, that you have almost got a perfect international line which could not be better laid out for an international line than it has been, when you look at the necessities of developing the country through which it passes. If we have performed (as we have done) the great *role* of setting an example to the world of the development of railways, we have also taught this great lesson, that it is folly to lay out bits of railways, and that there is no wisdom in the making of railways but one, namely, to develop an extensive and general plan in the first instance, and then to carry out that larger plan by degrees; after it has been systematically matured; and I say, with regard to these railways, I am satisfied that you can develop the resources of all these countries through which the railway has to pass, in such a manner as to add enormously to the wealth of civilized Europe, and the well being of the inhabitants, provided you will take all these points into consideration, including the wealth of the country, including our convenience, including strategical defence, and will not commit yourselves to any one branch until you have developed it as a part of the whole. Allow me, in conclusion, to say this one word. I know that if England will take the lead in this matter, there are other States in Europe who will give her cordial assistance in money, in political arrangements, and in support of every kind.

Mr. J. L. Haddan, M.I C.E.: In discussing this admirable paper, as one acquainted with every inch of the ground which Commander Cameron has lately

gone over, I must express my admiration at the remarkable way in which both in his book and lecture, he seems to have picked out the wheat from the chaff; a very difficult task when we consider that, owing to the short period he was in the country, a great deal of his information must have been obtained at second hand. No one, be he the best railway engineer living, which Commander Cameron does not pretend to be, could have hit upon a better line, from a railway surveyor's point of view, than he has done. It is certainly practical, as Mr. Austin's more elaborate surveys demonstrate, but nothing perhaps proves the inelasticity and weakness of ordinary railway construction more than the fact that the easiest line is always sought for, and not one which is necessarily either commercially or strategically the best; in this case the easiest route may be inadmissable, because it does not, in Sir John Adye's opinion, prove itself strategically of value, while in Mr. Andrew's opinion, it is not commercially the best either. The whole of the coast of Syria, between Alexandretta and the Suez Canal, is most formidable for shipping, there being no harbors of any kind; but as if to make up for it, Nature has created from Aleppo on the north down almost to Egypt on the south, an inland highway, along which you could almost drive a coach and four. Part of that natural highway is cleverly followed by Commander Cameron, viz., from Homs to Aleppo, and he thus taps the best part of the country. With reference to strategy, I beg to point out an important change in the question, one which the older advocates of the Euphrates Valley Railway, probably from long habit of one line of thought, have not noticed. They seem to forget that the bearings of the case are completely changed by the acquisition of Cyprus. It is no longer necessary, from a military point of view, to bring England and India into direct communication with each other—Cyprus being our representative now. It becomes simply a question of forming a triangle between Cyprus, Bayazid (on the Russo-Perso-Armenian frontier), and the Persian Gulf, so that from either end we can defend the Asia Minor frontier, as we are bound to do by the Anglo-Turkish Convention. This three-armed or Y-shaped line might follow the Cameron route from end to end, bifurcating at Mardin and passing through Diarbekr to Bayazid, which frontier town approaches it at right angles, a most important point in strategy. With reference to sending large bodies of troops by railway, a great deal of misapprehension exists as to the powers of a railway, both as regards its speed and capacity. The late Colonel Home, than whom there is no greater authority on military transport, showed that it would take longer to send an army corps to York from London by railway than it would for them to march, although there are several double lines in the example he quotes, and only a single line in this case. Single line railways as a military means of transport are, therefore, of little use, and are not fitted to carry any large number of troops, for to box men up in the way Colonel Champain described would, of course, be quite impracticable, except on an emergency. Referring for illustration to the Afghan campaign, it will be found that the enormous number of camels and mules employed transported stores for the troops, but not the men themselves, and the value of this line would be confined to doing similar duty—at far less expense—and with permanent advantage, creating means of transport instead of destroying them. Even for Cyprus, where is the grain to come from to feed that country but from Syria? It is a great mistake for the advocates of this line to talk of the profit to be made out of through traffic. Excepting for the mails the extra transphipments alone would be fatal if the bare fact did not suffice that no goods can afford more than 400 miles of railway transport, except the line in question enjoys a monopoly of route, which is not the case here. Should the Canal be blocked, then having this last point of transhipment, on the eastern side of the Canal, so much nearer to India as the Persian Gulf is than Suez, enables the few ships available on emergency in Eastern waters to do as much carrying work as the larger margin of supply the Mediterranean always affords. From a "transport" point of view speed is of no value—regularity is what is wanted. Speed only affects the first delivery, and regularity is necessarily jeopardized by hurry. A single line like this would not carry through goods at a

greater speed than one mile an hour, counting the full time they occupied the company's premises. In France the legal rate of transit for heavy goods works out but a little over half a mile an hour, and at a corresponding diminution in tariff even a slower rate is accepted. Speed and cheapness cannot co-exist on a railway; they *may* do so on the sea where there are no differences of level to be overcome. Having agreed that the Indo-European line is necessary, the next point is the labor question. Can you get men? I say most emphatically no! From an economical as well as a philanthropical point of view, a great many people hold that making railways by hand is a first-rate occupation for the peasantry. It has even been proposed to adopt these tenets in Ireland, the population of which is 169 to the square mile; but first-rate politicians have agreed that it is suicide in that country to take a man away from his plough. Now, we have the same question in Syria, but under less hopeful circumstances; for there the population is only 32 to the square mile, not enough to cultivate the soil at the best of times, while there are thousands of acres only wanting men to cultivate them to produce many hundred fold for themselves and for the State whose revenue is essentially derived from the soil. Mr. Consul Skene is of opinion such works would grievously affect the revenue. What worst investment can be imagined that employing in such a case manual labor in cutting off the tops of mountains and filling up the valleys? If you make up your minds to construct a railway in such districts, you must either use mechanical means for constructing earthworks, and even then none of the works will be completed simultaneously, or you must do away with them altogether, and the latter I have shown to be quite possible. One notable fact with reference to the construction of military railways, necessarily made by hand, is this: that a railway made by hand has four times as much stuff in it as a railway made with the usual English plant, viz., of rails, wagons and engines, &c. If you buy two chairs or tables, one made by hand and the other turned out by machinery, no doubt there would be the same amount of wood in both; but in railway construction it is not so, for in making a railway by machinery the wagons transport the earth from the cuttings to the banks, and it is therefore the custom in our profession only to pay for one, as the two birds are killed with one stone. But when you make a railway by hand, you cannot transport the stuff even a few yards, and every load of earth taken from the cutting must be thrown away and wasted, while every load of earth required for the banks has to be sought for afresh, and scraped together, perhaps, from a considerable superficial area. Owing, moreover, to the want of mining tools to blast the rocks with, cuttings are reduced to a minimum, and the banks correspondingly heightened, *i. e.*, practically doubled in depth. Now, since a 20-foot bank has four times as much in it as a 10-foot bank, it results that a railway made by hand will require about four times as much labor as if made by machinery; and, in addition, if in England, where coal, iron, and mechanical talent are drugs, £50,000,000 of railway capital pays no dividend, such works can hardly be expected to flourish in Mesopotamia.

Lieutenant-General Sir JOHN ADYE, R. A., K. C. B.—I am desirous of making a few remarks upon the lecture we have just heard by Commander Cameron, and am sorry to say he has not convinced me that either in a commercial or in a military point of view, it would be desirable that we should assist in making a railway through Asiatic Turkey as a means of communication with our Empire in India. As regards the commercial aspect of the question, our goods are now transported in vast quantities from the ports of England with ease and facility by sea through the Suez Canal, and within a month are landed in Bombay without transphipment, but if we adopted this proposed line, we should have to land our goods on the coast of Syria, where there are no good harbors, and where the country is unhealthy, and after a long journey by land should have again to embark them at the Persian Gulf, a country equally unhealthy, and devoid of good harbors and facilities. Would that, in a commercial point of view, be a desirable arrangement? Let me read a short extract from a letter that appeared in the *Times*, on the 11th

of December, 1879, signed W. H. I. The writer said:

"As a commercial enterprise the formation of such a line would, I venture to say, be a dead failure and prove sadly disappointing to any persons who had been foolish enough to embark capital in the undertaking in hopes of a return. That, after a steamer has been loaded and dispatched from London, Liverpool, or Glasgow, the whole of the cargo should be turned out at Beyrout or some other Syrian port, there loaded in railway trucks for conveyance through Mesopotamia, discharged out of those trucks at a port on the Persian Gulf, and a second time loaded on board a steamship for India, instead of being allowed to proceed to India direct in the original vessel which had sailed away from England, is an idea so preposterous in the eyes of all men of business that it may almost be dismissed without comment. Have your correspondents ever calculated, or attempted to calculate, the enormous expense which would be created by this extra handling of goods (to say nothing of the loss that would be caused by breakage or exposure), and compared this expense with the trifling gain which might possibly be derived from the shortening of the transit by five or six days?"

In a military point of view, I think there are great objections to the proposed route. In the first place, our troops are now transported with ease and comfort by sea in four weeks to Bombay, and it appears to me that that is the safest and most prudent course, which we, as a great naval Power, could adopt. But if taken in the way proposed, we should have to land our troops on the coast of Syria, and, after a long fatiguing journey of many hundred miles, should have again to embark them where there are no facilities, in a very unhealthy corner of the Persian Gulf. But there are greater military objections than that. This line of railway, if completed, would not belong to England, but would traverse the territory of another Power—that is, Turkey. Surely, it is not desirable that we should be dependent on another country for the line of our military communications with our Indian Empire. Another still greater objection is, that this line of railway would be open to danger at all points, while the Suez Canal is practically free from attack by land. By adopting such a proposal as that now under consideration, we should therefore not only be dependent on Turkey, but our line of military communications would run across the front of, and be in comparative proximity to, the armies of another great Power—that is, of Russia on the Armenian highlands. Surely, such an arrangement would not commend itself to the judgment of military men. In my opinion, therefore, the route would commercially be a failure, and in a military sense it would not only be useless, it would be a danger.

Capt. J. C. Colomb, R.M.A.—The last speaker has anticipated what I wished to say. The general question is that which has first to be considered. We have drifted into a good many mistakes in our time; we all know that, we have only got to consider what our Empire is at this moment to know it. We have a telegraph cable the wrong side of Africa, and we have our communications between two extremes of one of our great Colonies passing through a foreign country; therefore, I think of all things in considering a great question like this, we should really be careful to clearly understand whether, in its broadest sense, the proposed line is or is not desirable from an Imperial strategic point of view. And I must say, having looked into these questions, I entirely concur with Colonel Champain and the last speaker. I will not take up the time of the meeting by giving reasons which have already been given, but I should like to ask Commander Cameron if he would be kind enough to answer one question. In making a railway what we have to consider here is its strategical or military aspect purely, because commercially we have nothing to do with it, for this reason: that if it is a commercial speculation worth anything, we may depend upon it commercial men will take it up. In this Institution, I take it, we must only look at it from Imperial strategical ground. I confine myself very briefly, therefore, to this one remark. Commander Cameron spoke in rather an offhanded way, I think, considering our military resources as regards men, and when he said that if the Suez Canal was blocked, of course troops from

India and troops from England would meet at points in that proposed railway. I should ask him to consider, Have you got the troops? Are you going to make a great English line for strategical reasons without making preparations for its adequate defence? That is a very serious point. He said if the passage through the Suez Canal was stopped, we could carry on our traffic by that railway; but that, I consider, entirely depends in what way the Suez Canal is stopped. Is he contemplating the cutting of the sea communication by Alexandria, or between Alexandria and England, because if so, what becomes of your sea communication with the Mediterranean terminus of this proposed line? It appears to me that you would divide your power of defending your line of sea communication. We should never permit the stoppage of our communications through the Suez Canal; and to make your railway because you are content to think we may lose that route, is to my mind a mistaken policy. I simply ask Commander Cameron to explain how that land line of communication would enable us to recover our control of the Suez Canal when the control of the Suez Canal is really a naval question.

Mr. C. E. Austin, C. E.: I wish simply to say a few words on the commercial view of this question, for I know very little about the strategical part. With regard to the heat in railway carriages in these climes, I have had some experience in Brazil, and I did not find it so extremely oppressive as Colonel Champain thinks it would be. In Brazil we travel very easily. In Smyrna, again, where the heat at some times of the year is very oppressive, we travel very well in railway carriages, and we find no difficulty in so constructing our carriages as to keep the people cool inside. During the Russo-Turkish War we carried many thousand soldiers on the Smyrna and Cassaba Railway. With regard to the bugbear which drives all our commercial men away from railway speculations in Asiatic Turkey, so that without the aid of Government, and a guarantee on the money expended in the construction of these lines, they never will embark in them, it is the idea that you cannot work with the men of the country. The Kurds are tabooed; the Circassians are said to be people nobody can control. Midhat Pasha has been constructing roads in Asia Minor; and last April I had the pleasure of laying out the commencement of the Tripoli line, three miles in length, from the port of Tripoli to the town. I accompanied Midhat Pasha from Beyrout to Tripoli, whither he went more especially, because they told him 40,000 Circassians were collected at Tripoli, and there was much fear that they would become unmanageable. He went there and found 5,000 Circassians and Tartars, whom he set to work to make a road from Tripoli to Homs. We tried the Arabs, (the people of the country), and compared them with the Circassians; but the Circassians did much more work than any Arab, and they were taught with the greatest ease. They are the people on whom Midhat Pasha depends for making his carriages, and working the carriages on his roads. In every country that they go to, the Crim Tartars and Circassians introduce the carriage which does not exist in those countries. With regard to the Kurds, we have employed on the Smyrna and Cassaba Railway bands of Kurds; they are admirable laborers; they are much more easily taught than Greeks and Turks. The Turks are very good laborers too; but all the men we are the most afraid of, when they are turned to work, prove to be the best workmen we have. The best zaptiehs all over Syria are Kurds; the best country proprietors are Kurds; wherever you meet a Kurd you like him. I had a zaptieh with me, a sergeant, who traveled with me a long while. That man was a well-disciplined soldier; and although I was an Englishman and a Christian, and he a Mahommedan, he would come and pull off my boots in the evening, and would do any menial service for me, which an Arab would not willingly have done. He considered me as a friend of his master, and did not think of my religion in any way. With these facts in view, we must naturally infer that the Bedawee who inhabit the nomad districts of Syria and Mesopotamia, through which the proposed railway must pass, and who are only nominally Mahommedans, and much more liberal in their tenets than Mussulmans, would rather aid than hinder the construction and maintenance of the line. Then, as to commercial profits, I must say, Com-

mander Cameron's line, comparing it with the Euphrates Valley Railway from Alexandretta is a possible line, whilst the other is an impossible line. The gradients on his line are moderate, and there are no gradients against the traffic; whilst on the Alexandretta line it is stated that there are gradients of 1 in 13. The country being an agricultural country, the heavy traffic will consist in exports; and, in making a line of that sort, we must have no gradients against the traffic to the shore. The quantity of our import goods will be small in comparison, but it will be more valuable and pay more for carriage. The line proposed by Captain Cameron leaves out of the scheme a very large town, namely, Damascus. The traffic between Damascus and Baghdad is very large. Thinking, as I do, that there is not the slightest difficulty in setting these tribes to work, whether nomad, Arabs, Kurds, or Turks, I cannot see why you should not save 280 miles of railway, and go straight from Homs to Baghdad. Baghdad is the great emporium of the East, and the great object is to make the most direct communication with the west from that great emporium and the Persian frontier. By doing so you bring the traffic to Homs, which, in ancient times, was a very large town, and a very great center of commerce. From Homs the goods brought from the East can be dispatched over good roads either to Damascus or Aleppo, and the straight railway is sure of the traffic from Baghdad to both these towns as far as Homs. There is no difficulty in running across the steppes of Mesopotamia. They are as flat as a table, so that the line will cost comparatively little, and the traffic expenses be very light. However, into the details of construction this is not the moment to enter.

Mr. Trelawney Saunders: As you are quite aware, the naval power of this country can be exercised up to the shores of Syria on one side, and up to the head of the Persian Gulf on the other; and the simple question is whether it is desirable to complete the missing link, and connect those two points by a railway. In this Institute you may dismiss questions of commerce. If that missing link is to be supplied, you will probably conclude that it should be by the shortest and safest route. The author of the present paper has endeavoured to argue in favor of the Tigris as against the Euphrates, which unquestionably marks the shortest route. He has endeavored to persuade you that the Tigris is preferable, because it has more large towns upon it. But we must all recollect that we are not dealing in the present case with simply the supply of railway communication to certain towns in the Turkish dominions, but with the question—how this country and India can be most easily connected. It is admitted that we already have a line of communication *viâ* the Suez Canal. Very good; but is it desirable that we should depend under all circumstances upon one line of communication only, for you may almost put the line by the Cape of Good Hope out of the question? Most people agree that it is not desirable to confine communications of a great Empire to one line, and it is contended that the line of communication by the Persian Gulf and the Mediterranean should be made as an alternative to Suez. With regard to the present distribution of the population in the Tigris and Euphrates Valley, it must be in the remembrance of every one who has studied this subject that the time was when the Euphrates also had considerable towns at very short intervals along its banks; and there can be no question that with the establishment of a railway and the restoration of good government in Asiatic Turkey, the towns on the Euphrates would revive again. In fact, wherever you carry such a line of railway, population will follow it. It must be presumed that great facilities are offered by the Euphrates line, to account for the persistence with which its claims have been advocated for the last twenty years by Mr. W. P. Andrew. There must be good ground why a man of his railway experience and good judgment should so persistently adhere to that opinion. The Euphrates is not only the shortest line, but by keeping to the south bank, there are no affluents to cross, and having no rivers to cross, there are no bridges to make, nothing but a plain to traverse. There is also another advantage, to which I may point, inasmuch as it has been alluded to by a previous speaker of great eminence, I mean the advantage of having interposed between your railway and any enemy advancing from the north, two great rivers, which

would certainly be a great protection to the line south of the Euphrates. But there is a condition preceding that that has to be borne in mind in forming any opinion upon this question, and that is the following; No great public work could be undertaken in Asiatic Turkey in the present disturbed state of its administration. Therefore, it is to the establishment of good government in those countries that every one who is interested in opening up and improving communication through them with India should direct his mind at this moment. Everything should be done, I contend, to support any Government (I care not what party may be in power) in introducing into these regions, that were formerly the finest and fairest and best of the earth, that have still the natural fertility and productiveness and the industrious populations that would make them again the seat of wealth, and that need nothing but good government to restore the prosperity that made them formerly the seats of great Empires—on that point, the restoration of good government to those countries, already the opinion of the Powers of Western Europe has been brought to bear with great unanimity, and we should allow no differences of faction, no differences springing merely from political partisanship, to put difficulties in the way of that great object.

Mr. Trelawny Saunders—I am argu ing that we should all unite in promoting good government in Asiatic Turkey, and following upon good government, you may rely upon it, all questions of railway communication will very soon settle themselves. Whether you have a line by way of the Euphrates or Tigris, sooner or later that line will form a part of a general system of communication, which will connect Constantinople and Smyrna, as well as the ports on the Mediterranean, with Mesopotamia, the Persian Gulf, Persia and India. A certain boundary has been fixed on the frontier of Armenia, which we are engaged to maintain. Another boundary has been fixed upon the River Oxus, which we have defined. and are concerned in maintaining. Why are those boundaries fixed? They are fixed as barriers, beyond which a certain Power must not advance southward. But there is an interval between those two fixed barriers that remains unprovided for, namely, Persia. Is it intended that in that interval or through it any hostile Power may advance to the Persian Gulf, or to the mouth of the Euphrates, or to any other point between India and the Mediterranean that will suit its purpose? I think not, and therefore it must be clear and obvious, that whatever policy is directed towards the Armenian barrier at one end and the Oxus barrier at the other, must also be directed to the Persian link that lies between those two barriers. That is a matter necessary to be borne in mind, and to be brought into action, before you can connect India through Persia with the line of the Euphrates Valley. I am glad to find my friend Mr. Andrew adhering to the Euphrates Valley line, and if that line is to be extended to India, the ground must be made sure in the interval that lies through Persia.

Commander Cameron, in reply, said—Colonel Champain talks about the local traffic. I never would expect any railway to be paid for by its through traffic, but I believe the construction of the railway will attract people there who will settle on the ground and cultivate it, and will give us such an enormous traffic as will give a very good return on the railway. At present there are 400 tons, without the Aleppo trade, which comes from the line by Homs and Hamah every day, and goes coastwards. A short way further back, wheat can be bought for five to six shillings a quarter, and it is delivered on board ship at over forty shillings. I utterly put on one side any idea that any traffic by the Suez Canal is to be diverted on to our own line; it is to assist the Suez Canal, and I believe the opening of that railway will cause increased traffic through the Suez Canal. As to Bushire having no harbor, and ships of any draught having to unload three miles out, there is a little bar which might be dredged, and then there would be thirty feet of water close up to the town. We cannot make harbors without spending money, and if we are to have a great scheme like this, we must pay for making harbors. There is a very good opportunity for making a good harbor at Bushire, and also a magnificent harbor at Tripoli. I agree with Mr. Scott Russell about the railway going from

Constantinople. I do not think for our mails it is good to cross too many frontiers, but if the shortest route is by those frontiers, *perhaps*, it may prove best to cross them. If we cannot carry out the whole of this international scheme, why should we not make that section which is most important to us nationally, and let the other follow hereafter? Mr. Haddan talks about mechanical works in a railway. I suppose if we go out there, we shall employ the latest developments of mechanical science. The population are doing nothing for many months in the year, and a great portion of them are stowed together miserably in the towns, on account of taxation, who would, by the fact of this railway being constructed, be first drawn out in the open country to be constructors of the railway, and afterwards become cultivators of the ground. As for the troops, of course, the right way for our troops to go to India for all ordinary purposes is by the Canal; but if this line goes to Mosul, and I hope it is going to Persia some day, we may some day have war there, and then, by giving us the opportunity of bringing stores to such advanced points as Mosul and Diarbekr, the principal point in the defence of Kurdistan and Armenia, this railway will be of value to us. Then there is another thing. I never contemplate losing the command of the Mediterranean. I do not believe that England will ever lose the command of the Mediterranean or any other portion of the sea, but we know that dynamite and gun cotton are easily conveyed to the most extraordinary places, and in ten minutes' time anybody going through the Suez Canal might block it so that it could not be open for six months. It might happen that, at that particular time, all our ships might be on this side, and then, although we might take troops across the isthmus by railway, we should not have ships to carry them on. But if we could take them up to Bushire, we might in the meantime, telegraph to India to send ships. In answer to Captain Colomb, it is a great thing to be able to convey small bodies of troops rapidly, and thereby make them equal to large bodies of troops, that cannot be conveyed so rapidly. As to Kurds and Arabs, I may be prejudiced in favor of the Arabs. As for a Kurdish servant pulling off one's boots, I have gone into an Arab Shiek's tent, and he has pulled off my muddy riding boots himself, and you do not find hospitality like that in every place.

Mr. AUSTIN—I meant to say these were the people tabooed; the Arabs most likely would be better than they.

Commander CAMERON—Mr. Saunders still goes with Mr. Andrew. Now, I admire Mr. Andrew most thoroughly, but, at the same time, I must differ from him entirely. Iskanderoon is not a harbor, and a summit level of 2,200 feet has to be ascended in seven miles. A great portion of the Euphrates Valley is barren, and the population cannot live, while history tells us that, when the Emperors Julian and Cyrus the younger descended the Euphrates for a large part of the march, they were dependent on their flotillas for supplies. As for having two rivers instead of one to defend us, I should be very much ashamed if we wanted two instead of one; I should be very glad to use the Tigris by going down the right bank, but to go and put 200 or 300 miles and another river between us and a possible enemy, and leave a good position, I should be ashamed to run out of the way like that. Colonel Chesney quoted here, in July, 1857, "Europe is no longer the world. The key to "the possession of the world is the Valley of the Tigris, and not Constantinople." I hope that this railway will come to pass, and give us the command of that Valley of the Tigris."

IMPROVED VOLTAIC BATTERIES.—Some time ago M. Azapis suggested using a solution of chloride of sodium or of sal ammoniac for the acidulated water in contact with the zinc of a Bunsen battery, and the success of the change has led Mr. David Lindo, of Falmouth, Jamaica, to substitute sulphate of sodium for the dilute sulphuric acid in contact with the zinc of a Grove battery. Chlorine compounds might prove injurious in the Grove, and were therefore neglected for the sulphate of sodium. The substitution has given good results; no amalgamation of the zinc is required, and the intensity of the current is as great as where dilute sulphuric acid is employed. Moreover, the solution of sulphate of sodium answers well in the Bunsen cell.

THE FLUID DENSITY OF METAL.

ON THE FLUID DENSITY OF CERTAIN METALS.*

By Prof. W. CHANDLER ROBERTS, F.R.S., and T. WRIGHTSON.

THE authors described their experiments on the fluid density of metals, made in continuation of those submitted to Section B at the Swansea meeting of the Association. Some time since one of the authors gave an account of the results of experiments made to determine the density of metallic silver, and of cer tain alloys of silver and copper when in a molten state. The method adopted was that devised by Mr. R. Mallet, and the details were as follows: A conical vessel of best thin Lowmoor plate (1 millimeter thick), about 16 centimeters in height, and having an internal volume of about 540 cubic centimeters, was weighed, first empty, and subsequently when filled with distilled water at a known temperature. The necessary data were thus afforded for accurately determining its capacity at the temperature of the air. Molten silver was then poured into it, the temperature at the time of pouring being ascertained by the calorimetric method. The precautions, as regards filling, pointed out by Mr. Mallet, were adopted; and as soon as the metal was quite cold, the cone with its contents was again weighed. Experiments were also made on the density of fluid bismuth; and two distinctive determinations gave the following results:

$$\left.\begin{matrix}10.005\\10.072\end{matrix}\right\}\text{mean, } 10.039.$$

The invention of the oncosimeter, which was described by one of the authors in the Journal of the Iron and Steel Institute (No. II., 1879, p. 418),† appeared to afford an opportunity for resuming the investigation on a new basis, more especially as the delicacy of the instrument had already been proved by experiments on a considerable scale for determining the density of fluid cast iron. The following is the principle on which this instrument acts:

If a spherical ball of any metal be plunged below the surface of a molten bath of the same or another metal, the cold ball will displace its own volume of molten metal. If the densities of the cold and molten metal be the same, there will be equilibrium, and no floating or sinking effect will be exhibited. If the density of the cold be greater than that of the molten metal, there will be a sinking effect, and if less a floating effect when first immersed. As the temperature of the submerged ball rises, the volume of the displaced liquid will increase or decrease according as the ball expands or contracts. In order to register these changes the ball is hung on a spiral spring, and the slightest change in buoyancy causes an elongation or contraction of this spring which can be read off on a scale of ounces, and is recorded by a pencil on a revolving drum. A diagram is thus traced out, the ordinates of which represent increments of volume, or, in other words, of weight of fluid displaced —the zero line, or line corresponding to a ball in a liquid of equal density, being previously traced out by revolving the drum without attaching the ball of metal itself to the spring, but with all other auxiliary attachments. By means of a simple adjustment the ball is kept constantly depressed to the same extent below the surface of the liquid; and the ordinate of this pencil line, measuring from the line of equilibrium, thus gives an exact measure of the floating or sinking effect at every stage of temperature, from the cold solid to the state when the ball begins to melt.

If the weight and specific gravity of the ball be taken when cold, there are obtained, with the ordinate on the diagram at the moment of immersion, sufficient data for determining the density of the fluid metal; for

$$\frac{W}{W'}=\frac{D}{W'},$$

the volumes being equal. And remembering that W (weight of liquid) = W′ (weight of ball) + x (where x is always measured a + *ve* or − *ve* floating effect), there is obtained the equation:

* Abstract of paper read before Section C (Chemical Science), British Association meeting, York.
† See also *Engineering*, vol. xxviii., p. 329,

$$D=\frac{D'\times(W'+x)}{W'}.$$

The results obtained with metallic silver are perhaps the most interesting, mainly from the fact that the metal melts at a high temperature, which was determined with great care by the illustrious physicist and metallurgist the late Henri St. Claire Deville, whose very latest experiments led him to fix the melting point at 940° Cent. The authors of the paper showed that the density of the fluid metal was 9.51 as compared with 10.57, the density of the solid metal. Taking their results generally, it is found that the change of volume of the following metals in passing from the solid to the liquid state may be thus stated:

Metal.	Specific gravity, solid.	Specific gravity, liquid.	Percentage of change.
Bismuth	9.82	10.055	Decrease of volume 2.3
Copper.	8.8	8.217	Increase " 7.1
Lead...	11.4	10.37	" " 9.93
Tin....	7.5	7.025	" " 6.76
Zinc....	7.2	6.48	" " 11.10
Silver..	10.57	9.51	" " 11.20
Iron....	6.95	6.88	" " 1.02

PERMANENT WAY CONSTRUCTION.

From "Glaser's Annalen fur Gewerbe und Bauwesen" for Abstracts of Institution of Civil Engineers.

The author points out that if railway extension continues to proceed at the same rate it has been doing in this century, by the end of the next two centuries the combined products of all the forests in the world will be insufficient to supply the number of wooden sleepers required in railway construction; and that therefore any truly comprehensive solution of the question must provide a substitute that will comply with all the requirements it is possible to anticipate. Iron would not only satisfy these, but also afford profitable employment to the daily increasing industrial population of the principal countries of the world. The superiority in every respect of iron over wooden sleepers is not, however, universally admitted; to prove it, three questions must be satisfactorily answered, namely, those of cost, simplicity and safety.

As regards wooden sleepers, in the first place the best kinds of timber for sleepers are now not procurable in any appreciable quantity. The first cost and maintenance charges for wooden sleepers do not by any means show so marked a superiority over those for iron sleepers. According to Hilf's comparison between his system of longitudinal iron sleepers and wooden transverse sleepers, calculating fifty-six years as the life of the former, there is a yearly balance of 460 marks per kilometer (about £35 per mile) of line in favor of the iron sleepers, without calculating the value of the old material. The correctness of this estimate has, as far as is known, never been disputed. As regards simplicity of construction, no objection can be urged against wooden sleepers; as regards maintenance, there are many serious ones, involving safety to traffic, careful inspection, and labor in repairs.

Safety is endangered by the difficulty of keeping the line to gauge, owing to the imperfect hold the sleepers exert on the spikes, which is due to the variable holding properties of timber under different conditions, and the gradual destruction of the fiber from the blows transmitted through the foot of the rail during the passage of trains. A want of uniform rigidity of the road, due to the different ages of the sleepers produces conditions which seriously injure the rolling stock. The use of wooden sleepers does not recommend itself on the ground of cost and safety to traffic. Next the question of iron transverse sleepers demands attention; the advantages claimed for them are simplicity in construction and renewals, rigid maintenance of gauge, simplicity of drainage, durability, and handiness in time of war. The first cost, and cost of laying of both transverse and longitudinal iron sleepers is about the same. As regards maintenance, sufficient data are not procurable for a correct comparison, but it is presumable that with good ballast the

more equal distribution of the load on a longitudinal sleeper road would reduce the cost of maintenance.

Simplicity of construction is claimed for the transverse sleepers, on the grounds of greater handiness of the parts; but, then, again, the fact that one longitudinal is equal to four transverse sleepers should not be lost sight of. In laying curves, the longitudinal system certainly requires greater care and precision, and the work of renewing is more complicated; in time of war this is an acknowledged defect. A superiority in respect of maintenance of gauge is claimed for the transverse, but it is no less obtainable in the longitudinal system as exemplified in the Berlin municipal, Hilf, and Rhenish railway permanent way.

A decided objection to iron transverse sleepers is, that they do not afford the same hold on the ballast the heavier wooden ones do; that they require to be bent in order to give the proper cant to the rails, and in consequence are always liable to revert to their normal condition. Again, the fracture of a rail on a cross-sleeper system is attended with far more serious consequences than could possibly occur with the longitudinal system.

Longitudinal sleepers were the first made use of; transverse were not introduced until 1876. Even in the earliest times the following requirements were recognized as requisite for a perfect system of superstructure: (1) a head of a section sufficient to resist the wear; (2) a web deep enough to carry the weight; (3) a base sufficiently broad to distribute the load on the ballast. These conditions are perfectly realized by the longitudinal system alone, the best examples of which are furnished by Hilf, Haarmann, and the Rhenish railway.

The author then proceeds to discuss the relative advantages and disadvantages of the Hilf, Haarmann and Rhenish railway permanent way, to enumerate the evident objections to every system of transverse sleepers, and to combat and answer all objections to longitudinal sleepers, referring to the absolute necessity of greater attention being paid to the conditions of safety of a line, in consequence of the growing desire for an increased rate of speed, which likewise demands heavier engines, and these again introduce further elements of danger to the permanent way, straining it more severely and rendering cases of derailment more frequent and more serious.

A serious accident which occurred on the Cologne-Minden railway shortly after the speed on that line had been experimentally increased, drew attention to the subject and led to a series of experiments, as to the resistance offered by the various types of permanent way to the forces exerted by the rocking of a heavy engine. This also appeared a good opportunity for testing the relative efficiency of the various descriptions of permanent way. But the results of these experiments, however interesting, were not of a character to afford any practical solution of the question, as the actual conditions of the case were not correctly reproduced. Accordingly another plan was adopted, viz., an ordinary railway wagon (tare 4,500 kilogrammes), loaded with 18,500 kilogrammes of iron, was provided with a gallows, from which was suspended by a chain, 5 meters in length, a block of cast iron weighing 228½ kilogrammes, at a distance of 1.75 meters (wheel base of the Cologne-Minden locomotives) from the loaded axle. This weight, with a swing of 3 meters (equal to a vertical fall of one meter), was made to strike the inner side of the rail, the results of which are given in the four tables appended to the paper, and were registered by means of a lump of clay resting against the outer edge of the rail.

The apparatus and weights made use of in these experiments more than satisfy the conditions it was sought to reproduce, and afford a reliable test of the capacity of the various systems to resist the effects of the rocking of a heavy locomotive; the results are unfavorable to the system of transverse sleepers, but prove that a well-constructed permanent way with longitudinal sleepers is capable of providing perfect security in this respect.

The author's own comments on the behavior of the different types experimented on, and his deductions therefrom, are given in full, and conclude with a remark that though the behavior of permanent way in presence of such horizontal forces is certainly not alone conclusive

as to the value of any one system, since many other questions must necessarily also enter into the determination, yet the results of these experiments go a long way towards a solution of the question in favor of the use of longitudinal sleepers.

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN INSTITUTE OF MINING ENGINEERS.—The Autumn Meeting begins with the 25th of October, the programme is at this date, Oct. 17th, not at hand. The transactions of the last meeting are in process of distribution. In the last supply received from Mr. Thomas M. Drown, the Secretary, we notice :

"Investigations of the Ore Knob Copper Process," by T. Egleston, Ph.D.

"Notes on Gold-Mill Construction," by Augustus J. Bowie, Jr.

"Manganese Determinations in Steel," by Wm. Kent, M.E.

"Note on Black Band Iron Ore in West Virginia," by S. P. Sharples, S.B.

An important paper published in advance of the October meeting is :

"Chemical Methods for Analyzing Rail Steel," by Magnus Troilus, Chemist to C. P. Sandberg.

THE BOSTON SOCIETY OF CIVIL ENGINEERS.—The last published paper is that of the June meeting :

"Sheeting and Bracing Sewer Trenches," by Mr. William Whittaker.

POLYTECHNIC ASSOCIATION OF THE AMERICAN INSTITUTE.—The principal topic of the session of Oct. 1st was :

"The Various Systems of Raising Water," presented by the President, Mr. Thomas D. Stetson.

Oct 8th—The subject of "Ozone" was presented by Mr. P. Rudisch.

ENGINEERING NOTES.

ST. GOTHARD TUNNEL.—"I drove down alongside the St. Gothard Railway from the western end of the tunnel to Lake Lucerne, where the lines join those leading to Germany. What you will be most interested to know—how they are getting on with the slip in the mountain—I did not have a chance to ascertain, but I can give you some of the usual kind of travelers' information out of the guide book. The grade to and from the tunnel averages about 1 in 40. The tunnel, already open, and being lined, is 9½ miles long, and is 1⅝ miles longer and 600 feet lower than the Mt. Cenis tunnel.

"The interesting features which I saw were the stupendous works for getting up the rapidly rising gorge at Wasen. At this point, in a chasm between precipitous mountains, by means of five bridges and a tunnel, the road makes a double loup, and then by two tunnels it makes two complete circles in the mountain; in these tunnels the road crosses itself.

"The character of the work is most thorough. I never examined better railway masonry and drainage structures. I especially noticed the size of the stones (range work) and the mass of the various abutments and buttresses, thus adding the stability of weight to that of accurate workmanship. The rough torrent beds where freshets and avalanches come down, were replaced by round bottomed, inclined masonry chutes, often 100 feet or more wide, and running 1,000 feet up the mountain side. The iron bridges have rather short spans, and riveted connections invariably. The line is single, and the works do not look wide enough to add another line. I think that the average American capitalist would not like to be a shareholder in this railroad."—A. L. Holley to *American Machinist.*

THE MERSEY TUNNEL.—The operations in connection with the tunnel which the Mersey Railway Company are boring under the Mersey from Liverpool to Birkenhead are being rapidly pushed forward. On the Birkenhead side the permanent pumps are now in position; and continuous work day and night, with three shifts of workmen, has gone forward with the test or drainage heading. The length cut last week was eleven yards. This is all done by hand, with the aid of explosive gelatine, the confined space making the application of boring machines difficult. This heading is now well under the river, and no increase of water is perceptible. In fact the water does not now present any feature of difficulty, and engines keep it under even when working dead slow. The company's engineer and the contractor have now decided that the main tunnel shall go forward at the same time as the drainage heading, and permission has been obtained from the Mersey Dock Board to sink a second shaft close to the existing one in order to expedite this work, and this has already been carried down a considerable distance. On the Liverpool side less rapid progress has been made, owing to the fact that the upper part of the shaft had to be sunk through made ground, and also on account of the confined space on the quay within which the work has had to be carried on. The permanent pumps, however, are now fixed and at work, and they are found to exhaust the water with the engines working at the same slow rate as on the other side. As soon as a sump for the permanent drainage has been completed at the bottom of the shaft, which will be in about a week hence, the heading, which is already about a hundred yards in length, will be proceeded with. It is in contemplation to apply for permision to sink a second shaft on the Liverpool side, and this will shorten the time for the completion of the railway by a period of nearly six months.

RAILWAY NOTES.

RAILWAYS OF THE UNITED KINGDOM IN 1880.—Although the "Railway Returns" for 1880 have not yet been issued by the Board of Trade, some of the main features of the movement, as ascertained from the "Sta-

tistical Abstract for the United Kingdom from 1866 to 1880," has been given in the *Builder*. In the following figures the returns for 1879 can be compared with those of 1880 :

Length of railways open in the United Kingdom :

1879	17,696 miles.
1880	17,945 "

Total capital paid up in shares and loans :

1879	£717,003,469
1880	728 621,658

Number of passengers conveyed (exclusive of season-ticket holders):

1879	562,732,890
1880	603,884,752

Number of passengers per mile:

1879	31,800
1880	33,652

Total traffic receipts:

1879	£59,395,282
1880	61,958,754

Traffic receipts per mile:

1879	£3,356
1880	3,453

Working expenses:

1879	£32,045,273
1880	33,502,349

Net Traffic receipts:

1879	£29,731,430
1880	30,985,094

A WRINKLE IN PERMANENT WAY.—Not withstanding that many hundreds of so-called improvements in permanent way have been patented since railways became general, the old form of permanent way, consisting of a double-headed rail, cast-iron chair and wooden key, spiked or trenailed down to transverse timber sleepers, still obtains on the great majority of our lines. It is true that wrought-iron sleeper systems are at last being tried on some of them, but this is when our engineers find them largely coming into use on the Continent, particularly in Germany. We do not, however, propose a dissertation upon permanent way generally, our intention only being to place before our readers a very simple and practical improvement which has recently been effected in the ordinary permanent way of his line by the engineer of the Great Western Railway Company. This consists merely in reversing the chair and shifting the wood key from the outside to the inside of the rail. This re-arrangement gives several points of advantage, and in no way interferes with the working of the line, as the keys are clear of the flanges of the wheels of the vehicles. One of its chief advantages as regards the safety of trains is, that should a key work loose or even fall out, the gauge of the line will be rigidly maintained under passing trains. Should, however, such an occurrence take place with the keys on the outside, the gauge of the rails must necessarily be widened to some extent during the passing of a train, thereby constituting a source of danger. Then with regard to inspection, much time is saved to the plate-layer in his examinations, as he need only walk once down each pair of rails instead of twice. This sensible arrangement is, we recently observed, being adopted on the Great Northern Railway, and we doubt not engineers of other lines will follow the practice as opportunity offers.

RAILWAY RETURNS.—From the railway returns of England, Scotland, and Ireland for the year 1880, just issued, it appears that the total authorized capital up to the date of the return was £802,014,004. The total paid-up stock and share capital was £546,558,217, and the total raised by loans and debentures £181,758,631, making a gross total of £728,316,848. The length of line opened for traffic on December, 1880, was 17,933 miles. The total number of passengers conveyed, exclusive of season-ticket-holders, was 603,885,025 against 562,732,890 in 1879. The total of traffic receipts was £62,961, 797, showing a considerable advance on the £59,395,282 of 1879, and in fact being at the rate of £3,551 per mile instead of £3,356 in 1879, and £2,755 in 1866. The working expenses were £33,601,524, a million and a half increase during the year. The net receipts were £31,890,501, against £29,731,430 in 1879. The mean cost per mile over the whole system has risen from £40,518 in 1879 to £40,613 in 1880. The working expenses have fallen from 52 per cent. on the gross income in 1879 to 51 per cent. in 1880. The proportion of net receipts to paid-up capital is 4.38, against 4.15 in 1879.

CANADIAN RAILWAYS.—An important railway enterprise has been taken in hand at Montreal by Canadian and American capitalists. It is the building of a line, for which they have obtained a charter from the Dominion Government, from some point in the Canadian territory, on the Atlantic coast or Bay of Fundy, by way of Lake Megantic, Sherbrooke, Montreal, Ottawa, and French River, to a point on the east side of Lake Superior, receiving aid from Municipalities in Canada and the State of Maine. A meeting of shareholders was held August 30th to organise and commence surveys.

THE ST. GOTHARD RAILWAY.—The one-hundred and third report on the progress of the works of the St. Gothard Railway, reaching to the end of the first half of this year, has just been published. The principal and most difficult work, as we are aware, is the tunnel through the St. Gothard, of a length of 16,304 yards, or 9¼ miles. Its adit level has been driven this year, and more, the tunneling has proceeded for 13,215 yards, and been completed for traffic for 12,174 yards. No fewer than 3,319 workmen are employed in the tunnel, work proceeding uninterruptedly night and day. The contract value of the work done is £2,180,000, leaving still to be finished work to the value of £85,000. The quantity of compressed air used during the month of June for rock-boring machines and the locomotives employed in the carriage of materials and debris was 5,981,444 cubic feet per day. The temperature of the center of the tunnel was 29½° C. (85° Fah.), or 17° more than outside the tunnel. The quantity of dynamite used daily was 567 lbs. It may be remarked, in passing, that the temperature in the interior of the tunnel may possibly become lower, as has been the case in

the Mont Cenis tunnel, where it has fallen 7° or 8° C. during the last ten years.

RAILWAY ACCIDENTS AND BRAKES.—At the usual monthly meeting of the Foremen Engineers and Draughtsmen Association, on September 3d, Mr. John Batey read a paper on "Continuous Brakes." He stated that it was of the highest importance for the safety of the public that an efficient brake should be used for the purpose of stopping a moving train and preventing disasters. It had been clearly shown that the recent railway accident at Blackburn would have been mitigated if the Westinghouse brake could have been properly applied, and therefore he considered that the subject was one which demanded public attention. The Board of Trade had drawn up certain conditions which they considered necessary to make up a good brake. Those conditions were based on the experiments carried out from time to time by Captain Galton and others, and nothing short of them, he urged, should be adopted by railway companies. He believed that the reason why railway directors did not carry out the request of the Board of Trade with regard to continuous brakes was because so many failures had been recorded in the Blue book. Although none of those failures were productive of serious results, still they had a tendency to weaken the faith of the strongest believer in their efficacy, and that was doubtless a clue to the want of unanimity of opinion amongst directors as to the best brake for universal adoption. He contendep that a brake to be efficient should have a power equal to the weight of the train, for the purpose of balancing the coefficent of friction between wheel and rail sufficient to hold the wheel, but beyond that it was necessary that a certain power should exist for the purpose of checking the ultimate velocity of the wheel. Therefore, the absolute power applied was represented by time, multiplied by the power applied. He disagreed with Captain Galton, who contended that the power applied, just short of that which was necessary to stop the rotation of the wheels, was a better means of stopping the train than skidding, which Mr. Batey considered opposed to theory and practice. He believed it was utterly impossible to bring an unskidded train, traveling at the same rate, to a standstill in the same time and at the same distance as a skidded one. That point appeared to have been finally settled by the trials on the Midland Railway, carried on by the authority of the Railway Commission, under Mr. E. Woods and Colonel Inglis; and he concluded that it was necessary that a brake should be applied equal in power to each vehicle in order to stop it, and thus avoid the unpleasant bumpings. A brake to be efficient, should be capable of being applied instantaneously. He then alluded to the proposals to stop a train by applying the power on the locomotive, which he thought insufficient for the purpose, and would cause the carriages to "telescope." With regard to Sanders and Bolitho's and Smith's vacuum brake, he deemed it open to three objections, viz., the ease with which the vacuum might be destroyed by the difficulty of retaining the same; the want and waste of motive power by the injector being kept going constantly; and the great difficulty of keeping up steam, owing to the injector blowing away in the smoke box and damping the fires. He next proceeded to consider brakes worked by compressed air, and stated that he considered the Westinghouse the best, but that, however, was open to many objections. According to the Board of Trade returns for the half-year ending December, 31, 1880, that brake had made no less than 307 failures. He concluded by alluding at some length to a brake which he had patented, the advantage of which he contended consisted in its exceeding simplicity. It was less liable to get out of order, in consequence of its small number of parts, and was also economical.

IRON AND STEEL NOTES.

THE BILBAO IRON MINES.—By M. Baills.—The author gives descriptions and analyses of the three principal varieties of Bilbao ore—the campanil, vera dulce, and rubio, and remarks that the deposits probably consisted originally of homogeneous masses of carbonate of iron, interposed between beds of schistous grit below, and of limestone above, both of middle cretaceous age: and that the varying character of the ores now found appears to be due to the greater or less extent to which they have been weathered. Thus the deepest ore, now the vera dulce, is the least altered; that immediately under the limestone, the campanil, is more weathered; and that cropping out on the surface is the rubio, which contains the greatest proportions of water and of impurity. These typical varieties pass, insensibly, throughout the deposit, one into another.

The experience of wire rope tramways at the Bilbao mines has not been favorable; they are costly to maintain, and are liable to be interrupted by breakages of the rope, so that inclined planes, and ordinary railways, though more expensive, are on the whole preferred.

Some particulars are given at the end of the paper of the treatment of the softer ore (vera dulce) by the Chenot process, at the El Desierto works, near Barnacaldo. Each reducing furnace, used there for making spongy metallic iron from the ore, consists of two vertical brick retorts, 4 feet 7 inches by 1 foot in section, and 28 feet high. The retorts are heated externally by coal fires, and each of them is prolonged below by a sheet-iron cooler, 8 feet 1½ inch high. They are charged with ore and charcoal in alternate layers. The operation is carried on continuously, a portion of the reduced sponge being withdrawn at the bottom of the retort twice a day, and fresh ore and charcoal filled in at the top. The reduction of the ore and the cooling of the sponge require three days, and each retort thus yields about 0.72 ton of sponge every twenty-four hours, with a consumption of 1.27 ton of ore, 0.24 ton of charcoal, and 0.46 ton of coal. The cost per ton of the sponge is about equal to that of pig iron made at the same works. The sponge is made into balls of forgeable metal in

charcoal hearths, worked with blast at a pressure of 1.18 inch of mercury. Each hearth works in twelve hours, fifteen to twenty charges, consisting each of 202 lbs. of sponge and 55 lbs of charcoal. The cinder produced is very rich in iron; and 1 86 ton of sponge and 0.5 ton of charcoal are consumed per ton of bar made. The metal is very soft and malleable, and is specially used for nails for shoeing oxen.

The process seems likely, however, soon to be given up; it requires a very pure and a very rich ore, and the management of the operation is difficult. In working the sponge also into balls, the consumption of it is enormous. At the El Desierto works the number of furnaces in operation has been gradually reduced from six to two.—*Abstracts of Inst. of Civil Engineers.*

THE DEPHOSPHORIZATION OF IRON.—By Dr. K. List.—Dr. List's essay is an historical sketch of the attempts made to remove phosphorus from pig iron. He starts with the experiments of twenty years ago, and brings a very complete review of his subject down to the recent methods of Thomas, Gilchrist, and Snelus. He first notices briefly some of the wet processes which have been tried, with the object of freeing the ore from phosphorus, before smelting has been begun; treating them at considerable length the various processes, whether proposed, patented, or carried out, for removing the phosphorus during the process of reduction or after the metal has been reduced. The author has dealt with this extensive subject so concisely that an epitome of the paper would be little more than a list of names. It is not, therefore, attempted to abstract it, but simply to indicate its existence as a memoir which will be found of considerable value to any one requiring historical information upon the subject.

MAGNETIC IMPENETRABILITY OF IRON.—By J. Jamin.—The author recurs to the contested question as to the impossibility of causing magnetism to penetrate to considerable depths in iron and steel, and presents a series of experiments that he believes to offer a solution. There are placed, one above another, two equal bobbins wound with thick copper wire, separated by a third bobbin of fine wire which is connected to a reflecting galvanometer. A current in the two primary coils induces a current in the third and secondary coil. The arc shown by the galvanometer is recorded as a. There is then introduced into the three bobbins an iron tube $\frac{1}{2}$ of an inch thick. The primary current now induces a stronger secondary current, A; A—a measures the magnetization of the iron tube. Instead of the tube, a bar of iron equal in height is introduced, and the deflection A′ obtained. The bar is then placed in the interior of the tube, and a deflection A″ obtained. The following are one series of numbers:

A—a	49.5
A′—a	48.5
A″—a	54.0

A″—a was then obtained with the tube and bar placed side by side=59.5.

The author considers these and other experiments he details to prove that the same current communicates to the bar much less magnetism when the bar is contained in the tube than when it is exterior to it, and that the tube takes greater magnetism in the first case than in the second. And he definitely asserts that $\frac{1}{4}$ inch concentric depth of iron completely arrests the magnetic effect of an external spiral —*Abstract from Comptes Rendus for Inst. of Civil Engineers.*

THE EARLIEST CASTINGS IN IRON.—Cast iron is now in such general use that one might be apt to imagine that it had never been invented. But cast iron was not in commercial use before the year 1700, when Abraham Darby, an intelligent mechanic who had brought some Dutch workmen to establish a brass foundry at Bristol, conceived the idea that iron might be substituted for brass. This his workmen did not succeed in effecting, being probably too much prejudiced in favor of the metal with which they were best acquainted. A Welsh shepherd boy named John Thomas, had some little time previous to this been received by Abraham Darby into his workshop on the recommendation of a distant relative. While looking on during the experiments of the Dutch workmen, he said to Abraham Darby that he thought he saw where they had missed it. He begged to be allowed to try, so he and Abraham Darby remained alone in the workshop all night struggling with the refractory metal and imperfect moulds. The hours passed on and daylight appeared, but neither would leave his task, and just as the morning dawned they succeeded in casting an iron pot complete. The boy entered into an agreement with Abraham Darby to serve him and keep the secret. He was enticed by the offer of double wages to leave his master, but he continued faithful, and from 1709 to 1828 the family of Thomas were confidential and much valued agents to the descendants of Abraham Darby. For more than one hundred years after the night in which Thomas and his master succeeded in making an iron casting, in a mould of fine sand contained in frames and with air holes, the same process was practiced and kept secret at Coalbrookdale with plugged keyholes and barred doors.

ON THE RELATIVE POWER REQUIRED TO ROLL IRON AND STEEL.—By F. Braune.—In this paper some details are given of experiments made to determine the increase of motive power necessary to adapt a mill for rolling steel instead of iron.

The mill was a three high mill used for rolling deep joists, 60 feet long, and it was required to roll the same section and length in steel. The results of the experiments show that when the circumferences of the rolls are speeded for steel in the proportion of 14 to 11 faster than for iron. The power required for steel is about three times more than for iron. The author considers that rolling-mill engines are often made unnecessarily large; he recommends the proportions adopted by Van den Kerkhove of Ghent, whose engines are single-cylinder non-condens-

ing, with Corliss valve gear: the cylinder diameter is 914 mm, (36 inches), stroke 1,524 mm. (5 feet), revolutions per minute seventy-five, and weight of fly-wheel 50 tons These engines indicate 800 HP., with 60 lbs. steam cut-off at half stroke.

ORDNANCE AND NAVAL.

ARMOR-PLATE TRIALS IN FRANCE.—M. Francis Laur writes:—Experiments have recently been made at Gavres with armor-plates by three different firms—Creusot, Chatillon-Commentry, and Terrenoire. The experiments were conducted upon the same basis as former ones, reported in the columns of *Iron*. The only alteration was the dimension of the plates. Instead of the usual dimension of 4 square meters, the plates were only 1.20 meters square, the members of the commission being desirous to know if the smallness of the plates had any relation to the cracks usual with the largest plates. The results were the following:—

Creusot.—Steel plate (hammered). Penetration, 90 millimeters; slight cracks; excellent results.

Chatillon-Commentry.—Steel Plate Penetration, 320 millimeters; plate shattered in eight pieces; bad results.

Terrenoire.—Compound plate, manufactured without hammering or rolling of the steel, the molten steel being poured upon an iron plate. Penetration, 94 millimeters; cracks slightly more apparent than in the Creusot plate; good results.

The results of these trials are ascertained to be a great victory for Creusot. It will be remembered that at the last experiments, eighteen months ago, the steel plate of Creusot behaved so badly that the failure seemed past remedy. The compound plate of Messrs. Ch. Cammell obtained, on the contrary, a splendid success, and the Marine Department accordingly resolved to protect three ships with this new product, the Aciéries de la Marine, Chatillon-Commentry and Messrs. Marrel Frères being entrusted with its manufacture. These last trials have put a new aspect upon the question, The claim for superiority is now undecided between steel and the compound plates, but I think the question must soon be solved when these last-named will be tested.

THE "DETECTOR."—An exceedingly useful experiment is to be shortly carried out on board the "Sultan," armor-plated ship at Portsmouth. As is well known, all the ships which have been recently fitted out have been provided with electric lights for use as torpedo detectors. Many expedients have been tried for the purpose of enabling torpedo craft to approach a ship without being noticed; but though means have been adopted whereby the lights of their funnels and fires have been effectively screened, and the noise of the engines so deadened as to prevent their being heard until the craft have arrived within striking distance, it was found impossible to conceal the torpedo craft from the searching power of the electric beam, whatever color their hull is painted. It has been found, however, that the "detector," whether placed forward or on the bridge, is itself assailable, and the remarkable precision and range which have been developed by the Nordenfeldt and other machine guns have made it absolutely necessary that both the electric light and the men working it should be placed under protection. The experiments on board the "Sultan" will be undertaken with the object of ascertaining whether it be practicable to use reflected light. For this purpose the detector will be placed below, and the light projected through a tube upon a concave mirror which will be fixed on the bridge above, or on the mast, if necessary, and which will, by means of a pivot arrangement, be able to sweep the water in all directions. The electricity will be generated by a D-Gramme machine, and various lenses will be tried.

THE GREAT GUN TRIALS.—The repair of the hydraulic gear of the 100-ton experimental gun at Woolwich, which was thrown out of order on the first day's trial, was completed in time to permit the members of the Committee on Ordnance to resume the trials last Friday. The charge of powder was again 450 lbs. nominally, but actually only 448 lbs., the four cartridges of which it was composed being made up of precisely 112 lbs. each, for the convenience of the Royal Laboratory. For the manufacture of the prismatic kind of powder which has been adopted for these 100-ton guns, the Government pay upwards of 1s. per lb., and the addition of the shot, crushers, &c., brings the cost of each round up to the sum of probably £30, which is one of the reasons why the committee have been restricted to five rounds only. The three remaining of these were fired without a moment's pervertity. Five-and-twenty minutes were occupied in loading and preparing for the first round, twenty minutes in the case of the second, and fifteen minutes for the third, making exactly one hour occupied in the whole three rounds. This was performed in no way as a time test, for no official time was taken, and there was an entire absence of haste. In an emergency the gun can be readily fired the same number of rounds in less than a quarter of the time, but as a deliberate experiment, liable to many delays, the expediiion used at the trial was satisfactory. In actual service the guns of this size are never likely to be fired rapidly, one well-directed shot being sufficient to dispose of the strongest ironclad afloat, Major W. H. Noble, one of the artillerists on the committee, calculated that the 2,000 lbs. shot fired with a velocity of 1,570 feet per second would strike with an energy of 33,500 foot-tons at the muzzle, which, even at a mile range, would make short work of 3-feet armor. It was held to be remarkable that all this potentiality is generated with so little strain upon the gun, the pressures created by the improved powders being uniformly below 15 tons to the square inch, as was clearly demonstrated by Captain Hemans, R.A., the proof officer. Until recently 25 tons was the standard of security, and the reduction of pressure is most advantageous in facilitating the employment of large

charges, or even, if necessary, sacrificing something of a gun's strength. That the charge of the 100-ton guns cannot be extended beyond 450 lbs. was evidenced by the number of fragments of unconsumed powder picked up in front of the butts, but it is believed that by lengthening the barrel or increasing the bore—already 17¾ inches in diameter—a much larger quantity of powder could be profitably burnt inside the gun. Electricity was employed to ignite the charges, the battery being in the instrument room a quarter of a mile distant. The shots buried themselves in the sandbank to a depth of 60 feet, but the great gun was so perfectly under control that it recoiled only four feet, the hydraulic compressors acting most effectually in absorbing the superfluous force. Now that the experiments are completed, nothing remains but to convey the guns to their destinations in the Mediterranean fortresses; but the War Office has directed that the experimental weapon shall remain where it is for a short time, while the committee consider the results they have obtained, make their deductions, and report thereon.—*Iron.*

BOOK NOTICES.

Publications Received.

We are indebted to Mr James Forrest, Secretary of the Institution of Civil Engineers, for the following published papers of the Institution;

The Tide Guage, Tidal Harmonic Analyser, and Tide Predicter. By Sir William Thomson, LL.D., F.R.S.

Torpedo Boats and Light Yachts. By James Thorneycroft, M.I.C.E.

Description of a Bucket Dredger at the Hull Docks. By Robert Aspland Marillier, M.I.C.E.

Caissons for Dock Entrances. By Daniel Macalister.

Internal Corrosion of Cast Iron Pipes. By Mathew Buchan Jamieson.

On the Construction of Electro Magnets. By Paget Higgs, LL.D.

Three Systems of Wire Rope Transport. By William T. H. Carrington, A.M.I.C.E.

Railway Springs. By Benjamin Baker, M.I.C.E.

The production of Paraffin and Paraffin Oil. By Richard Henry Brunton, M.I.C.E.

Rapport du Chevalier Baillairge, Ingenieur de la Cite de Quebec, sur l'amelioration de son Aqueduc.

Instructions for Transmitting Communications by Heliotrope Signalling, arranged for use on the New York State Survey. By Olin H. Landreth.

Transactions of the American Institute of Mining Engineers.

New Method of Mapping the Anthracite Coal Region. By Charles A. Ashburner, Assistant Geologist.

Annual Report of the Operations of the Engineer Department of the District of Columbia. Under direction of Major W. J. Twining, U. S. Engineers.

History of the Cincinnati Waterworks. By Thomas J. Bell. Cincinnate: Robert Clarke and Co.

Contributions to the Theory of Blasting in Military Mining. By H. Hofer; translated by Captain Charles W. Raymond, Washington Government Printing Office.

Traite de Mecanique Generale. Par H. Resal. Tome Sixieme. Paris: Gauthier-Villars. Price $5.25.

This last volume of Resal's excellent work is devoted to practical engineering. The subjects treated are—Voussoir Arches, both Right and Oblique, Framed Wooden Bridges, Iron Bridges, Suspension Bridges, Draw Bridges, Chimneys, Foundations, Interior Navigation and Harbor Improvements.

Each of these topics is fully treated and beautifully illustrated; these latter, moreover, are designed especially to aid the engineer in comprehending the details of the construction. The cuts in this volume alone are more than five hundred in number, without including several large colored plates illustrative of European harbors.

Celestial Objects for Common Telescopes. By Rev. T. W. Webb. M.A., F.R.A.S. Fourth Edition greatly enlarged. New York: Industrial Publishing Company. Price $3.00.

The former editions of this are well known and highly valued by amateur astronomers. A full list of stars and nebulæ that are within range of ordinary telescopes is given, with the means of treating each object.

Epuration de La Houille, Criblage, Triage et Lavage. Par A. Burat. Paris: J. Dejey and Cie. Price $5.25.

This quarto volume is devoted to the various processes of cleansing, screening, and otherwise preparing coal for the market and for use.

Ten large folding plates exhibit the various machines on a scale sufficiently large to show most of the details.

This subject has only recently been regarded of sufficient importance to be made the subject of a separate treatise. But the numerous inquiries that have been made of late in reference to the best methods of coal working and separation have revealed the fact that the various processes have now assumed the importance of true engineering operations. The volume before us bears convincing evidence that nothing short of engineering skill of a high order could successfully design and operate such works as are described in it.

Practical Boat Building and Sailing. By Adrian Neison, C.E.; Dixon Kemp, A.I.N.A.; and C. Christopher Davies. Price $2.80.

The first of the subjects comprehended in the above title is treated by the first two of the trio of authors, and sailing, to which two-thirds of the treatise is devoted, is the work of Mr. Davies.

Throughout both treatises a plain and graphic method of instruction is employed, and the illustrations are very good and very abundant.

Sailing Rules of the London Sailing Club and of the Yacht Racing Association are given in an appendix.

ELEMENTS OF QUATERNIONS. By A S. Hardy, Ph.D., Professor of Mathematics, Dartmoth College. Boston: Gunn & Heath. Price $2 50.

To any one who has labored with the very few works extant upon this branch of mathematics, a glance at the opening chapter of Prof. Hardy's work will enforce the conviction that the author is an instructor of the first order.

We now have for the first time a text book on quaternions, which the student of only ordinary mathematical ability can read with satisfaction and profit.

The book is quite opportune. The subject must soon become a necessary one in all the higher institutions, for already are writers of mathematical essays making free use of quaternions without any preliminary apology.

It is safe to predict an eager acceptance of this work, among mathematical students throughout the country.

THE ANEROID: ITS CONSTRUCTION AND USE. Science Series No. 35. New Edition rewritten and enlarged. New York: D. Van Nostrand. Price 50c.; full roan, $1.00

The demand for this little manual exhausted the first edition.

The present volume is larger, and includes important additions.

The construction of the different kinds of aneroids is illustrated by cuts and text. The errors which are commonly made in using these instruments, and the means whereby the best results are obtained, are made matters of special treatment.

Numerous examples are worked out as aids to the novice in employing formulas and tables.

Two tables, not in the former edition, appear in this; a metric altitude table and a table of boiling points and corresponding barometric heights.

The increasing use of the aneroid warrants the belief that this book will be widely read.

THE SUN. By C. A. Young, Ph.D., LL. D., Professor of Astronomy, College of New Jersey. New York: D. Appleton & Company.

This is at the present time the latest issue of the International Scientific Series. Price $2.00.

American people have just reason to be proud of the fame of Dr. Young. His labors with the spectroscope, resulting in many important discoveries, have made his name familiar wherever there are astronomers or astronomical students.

The progress made in the study of the corona, in which the author first achieved distinction, is made the subject of an interesting chapter.

The typography and illustrations are of the same high degree of excellence exhibited in previous volumes of the series.

SECOND GEOLOGICAL SURVEY OF PENNSYLVANIA: SPECIAL REPORT ON CAUSES, KINDS AND AMOUNT OF WASTE IN MINING ANTHRACITE. By Franklin Platt.

The Legislature of Pennsylvania at its last session passed a joint resolution to the effect that an inquiry be made into the causes of the rapid exhaustion of anthracite—the possibility of more economy in the methods of mining, and the avoidance of the great waste and over production now prevalent.

The subject of *waste* in mining and subsequent handling is specially treated in the present Report. The result of the inquiry, though long known to mining engineers, will prove a surprise to the public generally. Not more than one-third of the coal lying in the ground can ever be brought to market by present methods of working and transportation.

The maps submitted with this report require a special mention. The method here employed of representing underground deposits was originated by Prof. Lesley, and was made the subject of an interesting paper before the American Institute of Mining Engineers, by Mr. Charles A. Ashburner, Assistant Geologist of the Survey. By this plan a geological mining map will represent:

1. Elevation above tide of the coal outcrop.
2. Dip of the bed.
3. Strike of the bed.
4. Depth of the coal basins.
5. Rate of rise or fall of basins along their axes.

6 Position of synclinals and anticlinals in the coal bed.

7. Data from which a vertical section may be made.

8. Data from which the absolute surface area of the coal bed may be obtained, and the tonnage of any section estimated.

A full description of the method, with examples of the maps are given in Mr. Ashburner's paper, which is published in a neat pamphlet.

MISCELLANEOUS.

A MIDGET MOTOR.—A little curiosity in engineering has been constructed in America by an ingenious clockmaker, Mr. D. A. Buck. This is in all probability the smallest steam engine in the world, for it is almost microscopic in its dimensions. The whole machine weighs only about a gramme, or 15 grains, and is entirely covered by an ordinary thimble. The stroke of the piston is a little over 2 millimeters or $\frac{1}{12}$ inch, and its diameter is something less than a millimeter and a half. Nevertheless it is built up of 140 distinct pieces fastened together by 52 screws; and three drops of water suffice to fill the boiler, and set the toy mechanism in motion.

CAPTAIN ABNEY recently exhibited at the Physical Society of London a number of photographic negatives taken by himself and Colonel Festin by radiation through thin sheets of ebonite. The light from the positive pole of an electric lamp was sent through a sheet of ebonite $\frac{1}{64}$in. thick, and photographs taken

showed the radiation to have a low wave length from 8000 to 14,000. The carbon points of the lamp could be photographed through the sheet, and Colonel Festin observed the sun's disc through it. The ebonite showed a grained structure, and different samples of ebonite gave different results, but all gave some result, in course of time at least; old ebonite, like that used in some of Mr. Preece's experiments, scattering the light more than new ebonite.

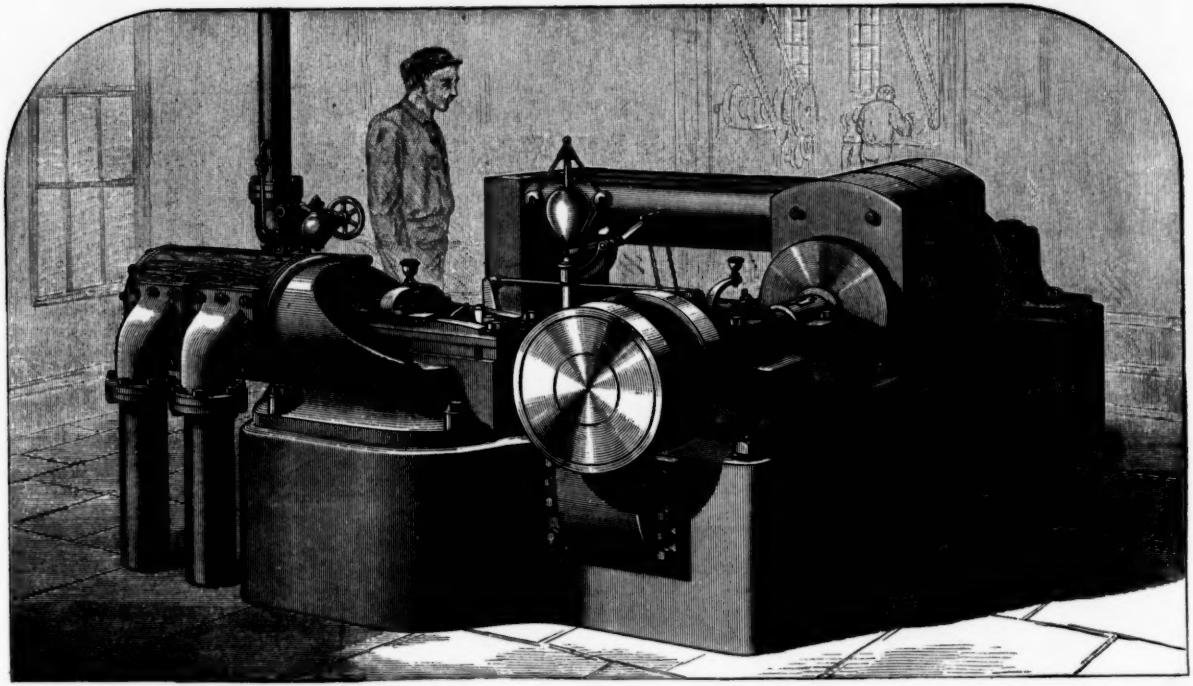
At a recent meeting of the Paris Academy of Science, a memoir on the temperature of the air at the surface of the ground and down to 36m. depth, also the temperature of two pieces of ground, the one bare, the other covered with grass, during 1880, and of the penetration of frost into these, was read by MM. Becquerel. Amongst other things the propagation of frost is shown to be slower in grassy ground than in bare ground. In the latter the rate increases very slightly with the depth, the propagation being very regular. In grassy ground the increase is very notable, and with increasing depth, the rate tends to come near that in bare ground. Each layer of ground is subject to two calorific effects; one due to variations of external temperature; the other to the action of deep layers which tend to give a constant temperature.

The influence of pressure on the electric conductivity of metal wires has been studied anew by M. Chwolson, and described in the bulletin of the Imperial Academy of St. Petersburg for March. M. Chwolson used a piezometer, giving pressures up to 60 atmospheres, the wire being wound round a glass tube, then passed through it, and the tube inserted in another, which was connected with the piezometer. The two wire ends were brought out through binding screws. Among the results at 3.8 C, the copper wire showed a relative diminution of resistance of about 0.0000013 by one atmosphere of pressure; a hard brass wire about 0 0000011; and a lead wire (at 7 deg. C) about 0.000011, or ten times more than brass. Pressing at 17 deg. C. the calorific action preponderates over the direct action of pressure for copper and brass, while the reverse occurs with lead. Moreover, the author proves, in the case of the brass wire, that the pressure causes change of the specific resistance, besides change of the resistance, through change of the length and thickness. Every relative change of volume involves a relative change of the specific resistance about 3.6 times as great.

One of the recently introduced substitutes for gold, which has become very popular in some of the jewelry and other manufactories of fine wares in France, is composed as follows: 100 parts, by weight, of copper of the purest quality, fourteen of zinc or tin, six of magnesia, three and six-tenths of sal ammoniac, limestone, and cream of tartar. The copper is first melted, then the magnesia, sal ammoniac, limestone, and cream of tartar in powder are added separately and gradually. The whole mass is kept stirred for half an hour, the zinc or tin being dropped in piece by piece, the stirring being kept up till they melt. Finally, the crucible is covered and the mass kept in fusion thirty-five minutes, and the scum being removed, the metal is poured into moulds and is then ready for use. The alloy thus made is represented as being fine-grained, malleable, takes a high polish, and does not easily oxidize.

When making some experiments under the direction of M. Chevreul, M. Niepce de St. Victor, who tried helio-chromic experiments on a large doll bedecked with jewels and resplendent with colored silk, made the remarkable discovery that black is not the mere absence of light, but is entitled to be considered a color of itself, and has a special chemical action of its own. The color of the sensitive plate was violet, and on this the camera impressed all the colors of the doll, including white; but as the blacks had also been impressed as black, it led to this experiment: A hollow tube, black from the absence of light, was presented to the camera, together with another article of a definite black color, with this result, that the former was represented by an unaltered state of the original violet color of the surface, while in the latter case a very deep black resulted.

Some extensive and important brake trials are in progress on the German State Rail ways. The brake question has long been receiving thorough examination by the German Government, and recently, in addition to numerous trains running ever since the Cassel brake trials in 1877 on various lines, trains have been specially prepared, fitted with the following six continuous brake systems, the inventor or his representative being in each case called upon to certify in writing that the vehicles are supplied with the most recent improvements:—Heberlein, Smith Hardy, Sanders, Westinghouse, Steel McInnes, and Carpenter. A series of trials on a portion of line near Halensee Station, on the Berlin Girdle Railway, will commence about the 29th inst., before a commission of engineers specially appointed to report on the subject of continuous brakes. The most practical portion of the trials will, however, commence immediately afterwards, when all six trains will be sent to work the express service between Berlin and Breslau for three or four months. The ordinary hand brakes on the vehicles are to be *plombe*, so as to ensure that in each case the special system on trial is alone used for all purposes, the cause of any departure from this rule, as well as any inconvenience or delay whatever in the usual traffic of the line resulting in any measure from the continuous brakes, being specially noted by an engineer told off to accompany each train throughout its journey. Captain C. Fairholme, in a letter to the *Times*, says: "The extreme care taken by the authorities of the Royal Railway Direction of Berlin, to whose charge the control of the entire arrangements has been committed by the Minister of Public Works, to ensure perfect impartiality, as well as the known high character of the German officials generally, combine to give these trials a special interest."



EDISON'S STEAM DYNAMO.